Researching:

Energy

Alliance of Scientific Organizations

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Scientific Organizations

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Message of Greeting

In recent years the processes of innovation have gained significant dynamic force. The "High-Tech Strategy for Germany" has been a major factor in this. Introduced in the last legislative period, it constituted the first national all-embracing concept for the research sector and has led to a new quality of cooperation between the scientific, business and political communities. In developing the High-Tech Strategy further, proven measures will be continued, but new points of emphasis are also being accentuated. The "High-Tech Strategy 2020" focuses on five major areas: climate and energy, health and nutrition, mobility, security, and communication. The aim is to make Germany a leader in the solution of urgent global problems by giving impetus to new technologies and innovations and by pooling the resources of science and industry.

The members of the Alliance of Scientific Organizations have a key role to play in the successful implementation of the High-Tech Strategy. So that science can perform its central task in research and development, in technology transfer and in the innovation process, the federal and state governments have agreed to continue with the Pact for Research and Innovation, and to support the Excellence Initiative and the University Pact. Together, these initiatives represent the biggest investment in research, science, innovation and education ever seen in Germany.

The scientific organizations are successfully addressing issues of the future and are advancing into new areas of research. The current series of brochures shows how well German research is placed to deal with the major future challenges. Each brochure is devoted to one of the main subjects identified in the High-Tech Strategy and uses engaging examples to illustrate the work conducted in Germany's research institutes. With their easy-to-understand descriptions of advanced research, these publications support the broad dialogue with the public on the pressing questions of our time.

Prof. Dr. Annette Schavan, MdB
German Federal Minister of Education and Research

Preface

Ladies and gentlemen,

People need energy. A simple statement, but one with serious implications – because the world's population is rising daily and each of us is consuming increasing quantities of energy. This poses challenges which simply cannot be ignored.

Modern industrial countries owe their progress in large part to the use of fossil energy sources. Oil, coal and gas keep business and transport moving and keep houses and offices warm. These natural resources are becoming depleted, however, and at the same time the demand for energy in the newly industrializing and developing countries is increasing sharply. The rise in energy consumption is also impacting badly on the environment.

When carbon fuels are burned, CO_2 is released. At the Copenhagen climate summit in December 2009 the world's governments acknowledged that CO_2 emissions are the main reason for global warming, and climate change is seen as one of the greatest challenges facing humankind. It is therefore clear that the use of fossil fuels must be reduced. If future generations are to have a reliable and affordable energy supply we must start now to change the way we produce and consume energy. But what are the alternatives available, and which ones should we embrace?

A general consensus exists that nuclear energy is still valuable as a bridging technology to take up some of the burden on the energy supply for a certain time. Despite considerable efforts and some remarkable progress, however, nuclear fusion power plants have not reached a stage of development where they can be counted on to contribute to the future energy supply.

In the future, renewables will hold a much more important position than they do now. They are based on comparatively simple technologies, but still require a lot of detailed development work. The fluctuating levels of energy generated, for example, pose completely new challenges for power grids and storage technologies. The plans drawn up by energy companies for large solar power plants in the Sahara and for international interconnection of wind farms in Europe show that the industry is not only facing up to its responsibilities for the future but also sees significant business opportunities in the use of renewables.

Efficiency technologies have a crucial contribution to make to the future energy supply. With each kilowatt-hour saved in the operation of electrical appliances, with every liter of heating oil not burned thanks to good insulation, with each liter of fuel that is not consumed on the road we reduce the amount of CO_2 discharged into the Earth's atmosphere – and thus alleviate the problem of climate change for us and future generations. We face the challenge not only of making technologies more efficient, but also of instilling in ourselves the discipline of using energy more responsibly.

The transition to a sustainable energy supply represents a central task for research, industry and politics. The German scientific organizations accept this challenge and are developing a broad spectrum of short-, medium- and long-term answers to this issue of such vital importance for humankind.

Our aim for this publication is to use selected examples to give an impression of the expertise and the wide-ranging approach with which members of the research community in our country are seeking to find solutions to problems in the energy sphere. We need this commitment, and the scientific community needs and deserves support from us all.

Sincerely,

Hans-Jörg Bullinger
President of the Fraunhofer-Gesellschaft

Contents

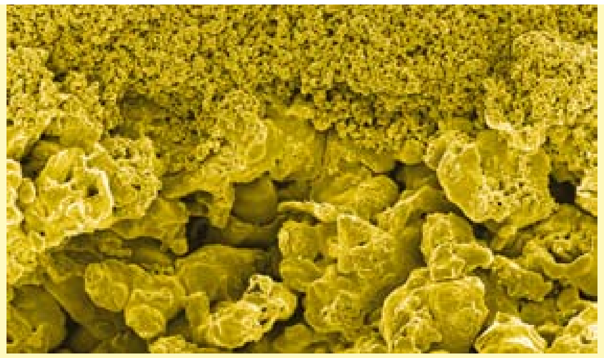
Electricity and heat from traditional sources

Around 60 percent of Germany's electricity is generated from fossil fuels, mainly coal. Worldwide too power generation is dominated by coal and natural gas. Today, both globally and in Germany, they account for more than 40 percent of total CO_2 emissions. Given the abundant deposits of coal around the world, this type of power generation, in which on average two thirds of the energy input is lost with the cooling water, will remain very important in future. The research and development being conducted to improve the efficiency of the technologies involved is therefore crucial.

Optimized turbine technology will help to generate electricity more efficiently in power plants.

In conventional steam power plants the greatest improvement potential resides in raising the steam parameters of pressure and temperature, which could increase the efficiency of new bituminous coal power plants from 46 to 50 percent. This would require new high-temperature materials for the steam generator and the steam turbines. New approaches include the externally fired combined cycle (EFCC) gas turbine system and a power plant process with binary elements such as multiple steam processes with potassium and water.

The combined cycle gas and steam turbine power plant has the potential to increase the electrical efficiency to a level of close on 60 percent. The hot exhaust gases from the gas turbines can be used to generate steam, for example, which is converted into electricity by a steam turbine. Or the exhaust gases can be used to heat the combustion air in a coal-fired power plant. Increasing the gas turbine inlet temperature by using new materials, for instance blades made of single crystals or ceramics, or new methods of cooling the blades, can raise the long-term efficiency

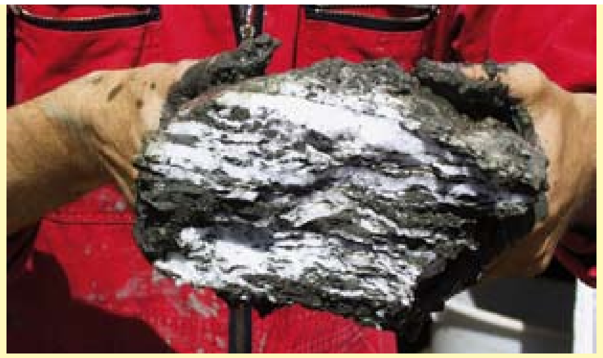


CO_2 splitting

Membrane technology to combat greenhouse gas

Fossil-fuel power plants with their carbon dioxide emissions contribute greatly to global warming. The emissions could be reduced by separating the CO_2 from the power plant gas stream and, for example, storing it below ground. Present separation processes, however, consume a lot of energy and as a result reduce the efficiency of the power plants. Filters made of new membrane materials could offer a better solution. Through the Mem-Brain research alliance the Helmholtz Association, in cooperation with partners, is pursuing the goal of developing membrane systems which will separate the gases energy-efficiently. Membrane technology therefore has an important role to play in climate-friendly energy generation.

Prof. Dr. Detlev Stöver
Forschungszentrum Jülich in the Helmholtz Association, Institute of Energy and Climate Research
www.fz-juelich.de
d.stoever@fz-juelich.de



Methane hydrate as raw material

Advantageous exchange of gas

Methane, the main constituent of natural gas, is the most environmentally friendly fossil energy source as gas power plants do not emit much pollution and are easy to control. There are immense deposits of methane hydrate on the seabed, which could be used to produce methane gas for energy generation. In exchange, the harmful CO_2 greenhouse gas could be stored as gas hydrate. In the SUGAR project (Submarine gas hydrate reservoirs: exploration, exploitation and transport), which brings together 30 partners from industry and science with support from the German Federal Ministries of Economics and Technology (BMWi) and Education and Research (BMBF), scientists aim to develop new technologies to exploit this potential.

Prof. Dr. Klaus Wallmann
Leibniz Institute of Marine Sciences at the University of Kiel
www.ifm-geomar.de
kwallmann@ifm-geomar.de

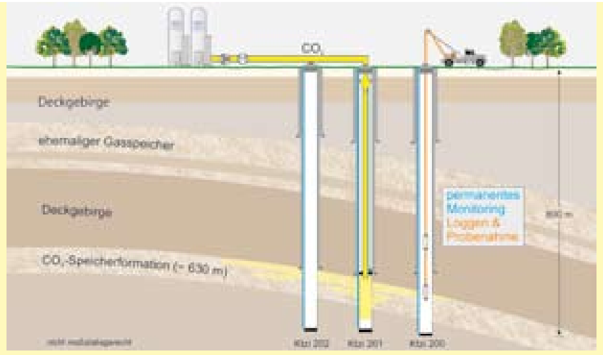
New power plant technologies will make it easier to separate and dispose of carbon dioxide.

High-temperature materials improve power plant performance.

to as much as 65 percent. The integrated gasification combined cycle (IGCC) is the most advanced coal power plant technology. Here coal is converted at high temperatures and pressures into a synthesis gas which can then be used in a combined-cycle gas and steam process to produce electricity. In combination with a high-temperature fuel cell, whose waste heat is used to gasify the coal, efficiencies of over 60 percent are conceivable.

If fossil fuels are still being used to generate electricity in 2050 – and according to present estimates this will be unavoidable – the increases in power plant efficiency just described will not be enough to achieve the climate protection targets. It will therefore be necessary to separate and store CO_2. Three separation methods are available: CO_2 separation from the flue gas (post-combustion), CO_2 concentration in flue gas by combustion with oxygen followed by CO_2 separation (oxyfuel) and CO_2 separation from the reformed synthesis gas from a gasification plant (pre-combustion). All these methods entail considerable additional expense, which would reduce the efficiency of the power plant by 10 to 15 percent. Intensive research could reduce this loss of efficiency by half over the long term.

It will be at least ten years before any of the three methods is ready for use on an industrial scale. In the meantime, suitable geological formations will also have to be found for storing the separated CO_2. Germany's options in this regard are mainly deep saltwater-bearing sandstone strata and exhausted natural gas fields – and these formations could also potentially be suitable for storing hydrogen or thermal energy. The capacity of these storage options in Germany should be enough to last for about two power plant generations, or about 80 years. The ideal solution would be to recycle the CO_2, but at present only 0.3 percent of the carbon dioxide emitted worldwide is put to use, and in Germany the figure is only 0.1 percent. Good ideas need to be developed to improve this situation.



CO_2 storage

Depot for greenhouse gases

The importance of reducing climate-relevant CO_2 emissions into the atmosphere is becoming more and more acute. New technologies are being developed to monitor and predict the storage of the gas in porous rock deep below ground near Ketzin in Brandenburg. At a depth of just over 600 meters porous sandstone strata are deposited in an uparched geological structure. These storage rock beds are covered by almost impermeable layers of anhydrite and argillite. Measurement data collected from these formations make it possible to evaluate the prediction models used to assess the extent to which the CO_2 will spread out underground and the safety of the reservoir. The creation of the geological CO_2 store can thus be regarded as an example for future demonstration projects.

Dr. Michael Kühn
Helmholtz Centre Potsdam –
GFZ German Research Centre for Geosciences
www.gfz-potsdam.de
michael.kuehn@gfz-potsdam.de

Waste gas cleaning

Bioreactor binds CO_2

Carbon dioxide is a climate-damaging gas. It is released during combustion processes and ideally should be captured where it arises, e.g. in the power plant. One possible way of doing this would be to recycle the gas by means of photosynthesis, because plants and algae need CO_2 to form organic compounds with the aid of sunlight. In cooperation with Subitec GmbH, Fraunhofer research scientists therefore developed an adaptable, low-cost photobioreactor. The algae living in it extract the CO_2 from the flue gas arising in a natural gas power plant and in the process of converting it produce vitamins, fatty acids, pharmaceutical agents and, in particular, biomass.

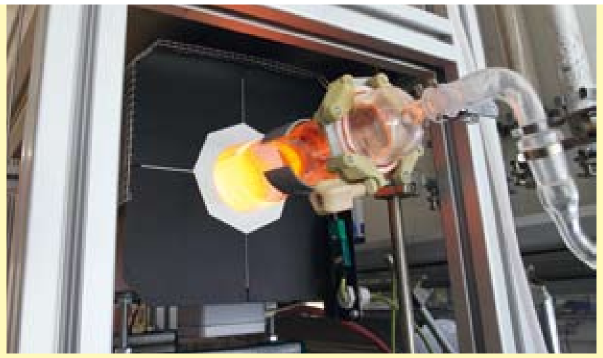
Prof. Dr. Walter Trösch
Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
www.igb.fraunhofer.de
walter.troesch@igb.fraunhofer.de

Materials research

New materials increase efficiency

Metallic materials able to withstand surface temperatures in excess of 1200 °C under high mechanical loading in the air atmosphere could considerably increase the performance and efficiency of power plant turbines. A research group from Darmstadt, Bayreuth, Bochum, Braunschweig and Siegen, funded by the German Research Foundation (DFG), is applying principles of metal physics in the search for alloys which meet the requirements profile of good resistance to oxidation, adequate toughness and formability as well as high creep resistance. Currently the focus is on the two alloy systems Mo-Si-B and Co-Re, whose melting points are more than 250 °C higher than those of the nickel-based superalloys currently used.

Prof. Dr.-Ing. Martin Heilmaier
TU Darmstadt, Materials and Earth Sciences Department
www1.tu-darmstadt.de/fb/matgeo
m.heilmaier@phm.tu-darmstadt.de

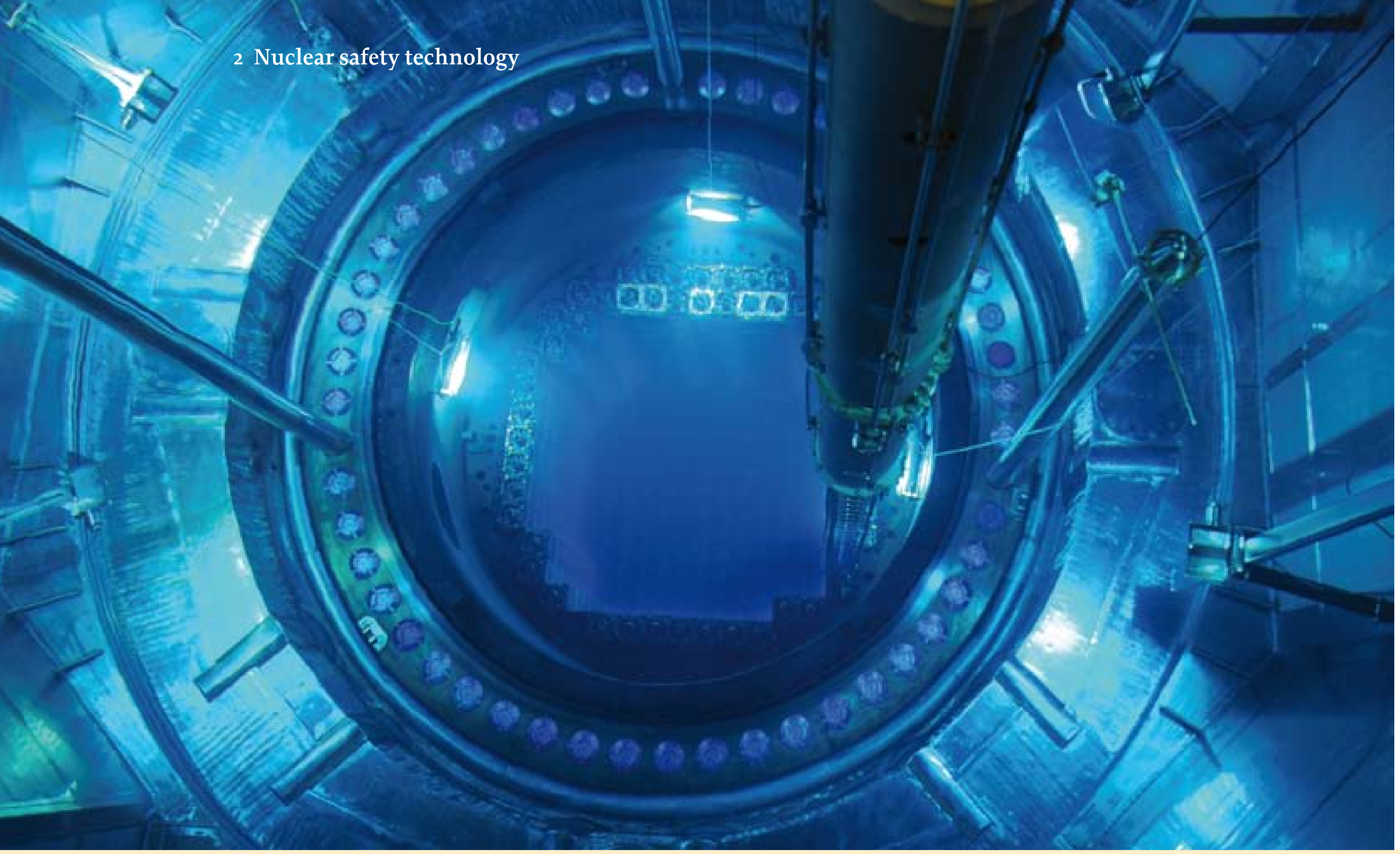


Materials research

A material that leaves heat cold

The hotter, the better – at least as far as the efficiency of power plant turbines and internal combustion engines is concerned. Coatings of light and very stable ceramics, developed by research scientists at the Max Planck Institute for Solid State Research in Stuttgart and the Fraunhofer Institute for Silicate Research ISC, allow the temperature and thus the efficiency of combustion processes to be distinctly increased. The material is made of silicon, boron, nitrogen and carbon and can withstand more than 1400 °C, where today's best ceramics can only handle 1200 °C. The research scientists in Stuttgart have achieved this jump in temperature by pursuing a completely new approach and endowing their ceramic with an unordered, net-like structure.

Prof. Dr. Martin Jansen
Max Planck Institute for Solid State Research, Stuttgart
www.fkf.mpg.de
m.jansen@fkf.mpg.de



Safe bridge to the future

Nuclear energy continues to make an important contribution to power generation in many countries because it offers attractive advantages as a climate-protecting, low-cost and reliable part of the energy supply. Given the complex technology involved, it is essential to maintain and develop the scientific expertise in this field.

Cooling pond of a nuclear power plant.

In Europe nuclear energy is more prevalent than in any other region. There are 195 nuclear power plants supplying around 31 percent of annual electricity demand. In Germany nuclear covered about 11 percent of primary energy consumption in 2009. Ecology, economy and safety are key criteria for the long-term operation of present facilities. Advanced Generation III light water reactors based on existing commercial power plants are now commercially viable and will form the basis for new build in the coming years. The development of fourth-generation nuclear facilities, which could be needed in the second half of the 21st century, is the current focus of international research, the main objective being to achieve further improvements in safety, fuel utilization and waste minimization.

Excellent scientific and technical knowledge is absolutely essential for guaranteeing the high safety standard of nuclear power plants, the safe treatment and disposal of radioactive waste and the protection of people from radiation.

Disposal technology

Safety for the long term

Nuclear power generation produces radioactive waste which has to be converted into a permanently stable form for safe disposal. One approach is to immobilize highly radioactive liquid waste in a glass matrix, but this represents a major technical challenge. Scientists and engineers at the Karlsruhe Institute of Technology (KIT) succeeded in developing to technical maturity a vitrification process which is based on a liquid-fed ceramic furnace. This technology has been used to permanently stabilize 60 m³ of highly radioactive liquid waste. At the Forschungszentrum Jülich (Jülich Research Center) further materials and processes are being developed to ensure the future safe disposal of radioactive waste.

Dr. Walter Tromm
Karlsruhe Institute of Technology (KIT)
in the Helmholtz Association
www.kit.edu
walter.tromm@kit.edu

Reactor safety

Computer simulation of incident scenarios

Multi-phase flows play an important role in reactor safety research, e.g. for predicting the behavior of complex water-steam mixture flows in incident scenarios. The theoretical models for the fundamental phenomena involved are validated at the TOPFLOW facility of the Helmholtz-Zentrum Dresden-Rossendorf (HZDR), where flows at pressures and temperatures similar to those in a nuclear reactor can be studied by means of innovative imaging measurement technology. For example, to describe a postulated loss-of-coolant accident and assess the effectiveness of safety systems, high-resolution CFD codes are used. The models developed for this are examined in single-effect tests and large-scale experiments, some of which are conducted in Germany.

Dr. Walter Tromm, Dr. Uwe Hampel
Karlsruhe Institute of Technology (KIT) in the Helmholtz Association and the Helmholtz-Zentrum Dresden-Rossendorf (HZDR)
www.kit.edu, www.hzdrde
walter.tromm@kit.edu, u.hampel@hzdr.de

Containers for the safe storage of radioactive waste.

In the interests of social health and welfare, scientists are conducting prophylactic research in three specific areas of nuclear safety: nuclear reactor safety, safe disposal of nuclear waste and radiation protection. For the safety of nuclear reactors, intensive study is going into the processes and phenomena occurring in incidents within and beyond reactor design limits. This not only involves describing the possible course the incident will take but also developing measures for quickly bringing the incident to an end or at least keeping it within the confines of the plant. For safe nuclear disposal, research work is being conducted on the immobilization of highly radioactive waste, on the reduction of radiotoxicity and on the long-term safety of nuclear waste repositories. Radiation protection research deals with radionuclides in the environment, their entry into and transmission in the human food chain and with radiation exposure through the use of radionuclides in medicine.

Concepts for the future

Measurement technology for liquid metal flows

Flows of liquid metals are attracting increasing interest in nuclear technology – as coolants for new reactor concepts, such as the sodium-cooled rapid reactor, or for transmutation facilities. The latter could convert long-lived radioactive elements into short-lived materials and thus help to address the issue of final storage of highly radioactive waste. The measurement and monitoring of metal flows is key to the safe operation of these facilities. At the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and the Karlsruhe Institute of Technology (KIT) new methods have been developed for conducting contactless measurements at high temperatures. The same measurement techniques can also be used in foundries producing steel castings and in silicon crystal growing.

Dr. Gunter Gerbeth
Helmholtz-Zentrum Dresden-Rossendorf (HZDR)
www.hzdr.de
g.gerbeth@hzdr.de

Disposal technology

Decontamination of nuclear graphite

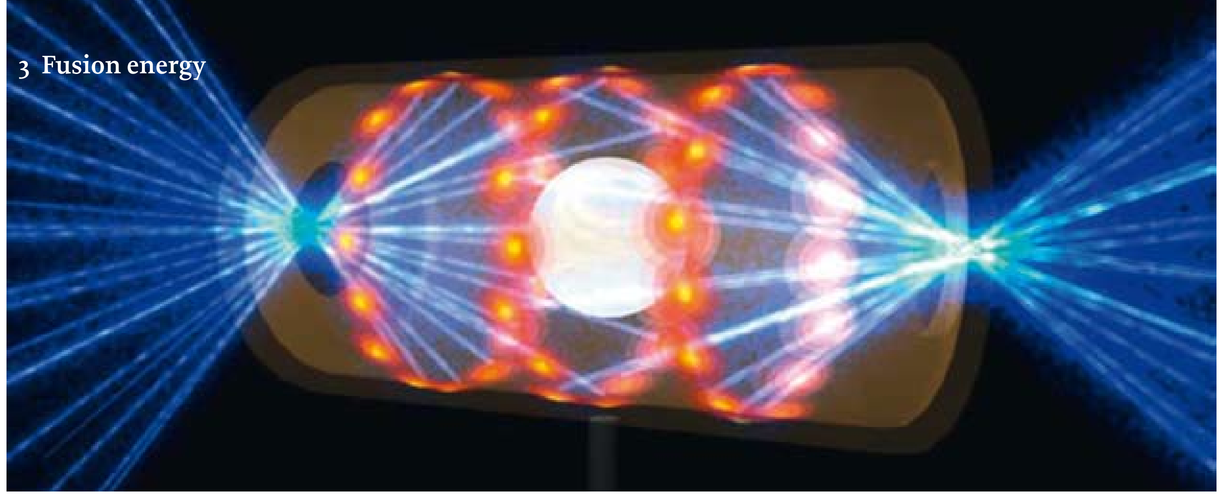
More than 250,000 tons of radioactive graphite from closed-down nuclear reactors is being stored around the world. The nuclear graphite project conducted by the Forschungszentrum Jülich (Jülich Research Center) has the aim of developing scientific concepts for the safe final storage and recycling of reactor graphite. The project focuses primarily on basic research and application-oriented methods for decontaminating the graphite. The scientists have succeeded in removing fission and activation products from graphite samples by employing chemical reagents to form volatile or soluble compounds with the radionuclides without attacking the graphite matrix.

Prof. Dr. Dirk Bosbach
Forschungszentrum Jülich in the Helmholtz Association
www.fz-juelich.de
d.bosbach@fz-juelich.de

Satisfying future hunger for energy

Nuclear fusion as a concept is based on the sun, the aim being to utilize the principle behind the sun's generation of energy in a controlled manner on Earth. To this end, extreme physical conditions have to be created, and this involves highly complex technology. The vision is to create a fusion reactor that will deliver a safe, economic, environmentally friendly and continuous output of energy which can be used to generate electricity. It is only through international cooperation that the massive research effort required can possibly be undertaken.

3 Fusion energy



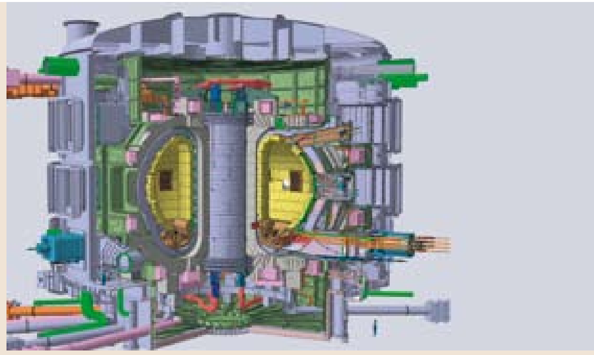
Fusion power plants imitate the sun to produce energy.

The starting point for nuclear fusion is a mixture of deuterium and tritium at a pressure corresponding to about 1/250,000 of atmospheric pressure at the Earth's surface. The 1000 m³ vacuum container in the reactor therefore only contains a few grams of the mixture. For just a few seconds a startup heater radiates an output of 50 to 100 megawatts into the combustion chamber. This heats the fuel mixture to approx. 100 million °C and turns it into plasma. To prevent it from touching the wall of the vacuum container, the plasma is enclosed in a spiral magnetic field. The fusion reactions in the plasma release high-energy helium nuclei and neutrons. The movement of the electrically neutral neutrons is not influenced by the magnetic field. They are decelerated in the reactor shell and the heat generated is fed into a conventional power-generation cycle via a coolant. The electricity is then produced by a turbine and generator as in a conventional power plant.

Compared with other energy sources, nuclear fusion offers a huge energy yield. The fusion of one gram of deuterium-tritium mixture releases an energy output of 2600 kWh, which is equivalent to the combustion of 10 tons of coal. The fuel reserves in the Earth's crust and oceans are enough to cover the entire world's energy consumption for millions of years. Unlike the fossil fuels oil, natural gas and coal, the water and lithium (from which tritium is bred) required as raw materials are evenly distributed around the world, which means conflict cannot arise over access to energy sources. Also, a fusion power plant possesses favorable safety characteristics – even in the event of a total coolant failure the system would not burst. What's more, the fusion power plant itself does not emit any climate-damaging gases.

Terrestrial nuclear fusion has been possible for a long time on an experimental scale. Around the world scientists are now working on the development of fusion power plants. German fusion research is part of a program that is coordinated and funded at European level (EURATOM).

Nuclear fusion technology is highly complex.



ITER research reactor

A step towards a working power plant

The biggest current project in fusion research is the ITER experimental reactor built in Cadarache, a tokamak type plant. The aim is to produce a plasma with a net energy surplus for the first time, releasing 500 megawatts of fusion power – ten times the heat input. The ITER will also test main components of fusion reactors in operation. A key task here is to develop concepts for the blanket which encloses the plasma and performs three tasks – it converts the neutron energy from the fusion reaction into usable heat, breeds the tritium fuel from lithium by capturing neutrons, and protects the superconducting magnets from neutron and gamma radiation.

Dr. Dirk Radloff
Karlsruhe Institute of Technology (KIT)
in the Helmholtz Assocation; FUSION Program
www.kit.edu
dirk.radloff@kit.edu

Tokamak and stellarator

The right type for particle fusion

Sometimes a more complex solution proves to be the easier option – this might also be true of nuclear fusion power plants. For this reason, along with their work on the most developed type, the tokamak – of which the ASDEX Upgrade in Garching is one example – physicists at the Max Planck Institute for Plasma Physics are also conducting research on the stellarator. Its design is more complex than that of the tokamak because it generates the magnetic field enclosing the plasma using a very elaborate coil system, but it is easier to operate continuously. After extensive preliminary work, the Wendelstein 7-X stellarator is currently being built in Greifswald. It will allow scientists to test whether the advantages of this type of plant can be realized in actual practice.

Prof. Dr. Günther Hasinger
Max Planck Institute for Plasma Physics, Garching and Greifswald,
Associate Member of the Helmholtz Association
www.ipp.mpg.de
günther.hasinger@ipp.mpg.de

Fusion energy

On the way to the international fusion reactor

The success of the ITER fusion reactor and subsequent power plants depends heavily on the material and design of the combustion chamber's inner walls. Scientists at Jülich are experts on the plasma-wall interaction, in which the fusion plasma at a temperature of over 100 million °C and the reactor wall influence each other. For nuclear fusion to take place successfully, the plasma must be enclosed by magnetic fields, which, however, must also let the products of the fusion reaction pass through. For this purpose, the edge-layer plasma is guided to certain areas of the wall called divertors. These were co-developed and tested in Jülich. They have to withstand heat flows of more than 20 million watts per square meter and are made of solid tungsten and graphite.

Dr. Ralph P. Schorn
Forschungszentrum Jülich in the Helmholtz Association,
Institute of Energy and Climate Research
www.fz-juelich.de
r.p.schorn@fz-juelich.de

Nuclear fusion and nonproliferation

The security-policy dimension

Nuclear fusion is a highly promising new energy source. As with conventional nuclear technologies, however, the risk of military misuse cannot be excluded. In cooperation with TU Darmstadt, interdisciplinary research is being conducted into this proliferation risk. Using computer simulations, physicists are calculating the quantity and quality of weapons-grade material that a commercial fusion reactor could produce. Political scientists are looking into the control mechanisms that could be used to prevent military misuse. The research project is developing input for the regulation of fusion technology to meet technical and nonproliferation requirements.

Prof. Dr. Klaus Dieter Wolf
Peace Research Institute Frankfurt (PRIF), TU Darmstadt
www.hsfk.de, www.tu-darmstadt.de
wolf@hsfk.de

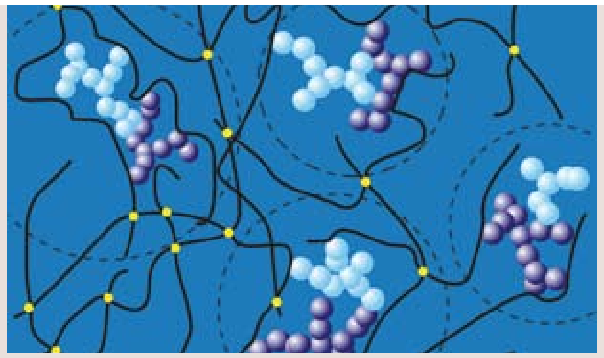
Higher performance with less waste

When final energy, such as electricity or gasoline, is converted into useful energy, such as light and motion, about one third of the input is wasted. And frequently the useful energy is not even really needed, e.g. when TVs or sound systems are on standby or lights are burning in empty rooms. Needs could often be met by other techniques that do not require energy consumption, for instance by using daylight instead of artificial light. Things have improved over recent years, but research and development can still open up lots of valuable energy efficiency potential.

LEDs produce light of any color very efficiently.

A typical example of energy wastage is the old incandescent light bulb which converts electricity into light with an efficiency of only about 5 percent. Compact fluorescent lamps achieve an efficiency of about 20 percent, but they are not equally suitable for all applications. In the near future the means of illumination used hitherto will be replaced by light-emitting diodes as single-point lighting. LEDs offer high energy efficiency, a long lifespan, good switching strength, brilliant light and excellent design versatility. Dimmable linear fluorescent lights with electronic ballasts are similarly energy-efficient. In a few years' time organic light-emitting diodes (OLEDs) will come onto the market as large-area light sources.

Similar increases in electrical efficiency have also been achieved for small electric motors. Whereas conventional low-power motors (approx. 100 watts), as used e.g. in heating system circulating pumps, refrigerators and freezers and especially in commercial and industrial applications, have an efficiency of about 40 percent, the efficiency of the new, electronically controlled



Materials research

Energy efficiency with new elastomers

In the NanoElastomer project, conducted under the German Federal Ministry of Education and Research's NanoMobil innovation program, scientists at the Leibniz Institute for Polymer Research in Dresden looked for ways of applying new approaches in nanomaterial technology to improve the properties of tires and other technical elastomer products for the automotive industry in terms of safety, comfort and sustainability. To this end, they identified new fillers with structures measuring less than 100 nanometers and studied their interactions with the rubber matrix and with each other. In addition to ecological advantages deriving, for example, from a longer service life and lower tire rolling resistance, better adhesion and braking characteristics were achieved on wet and wintry road surfaces.

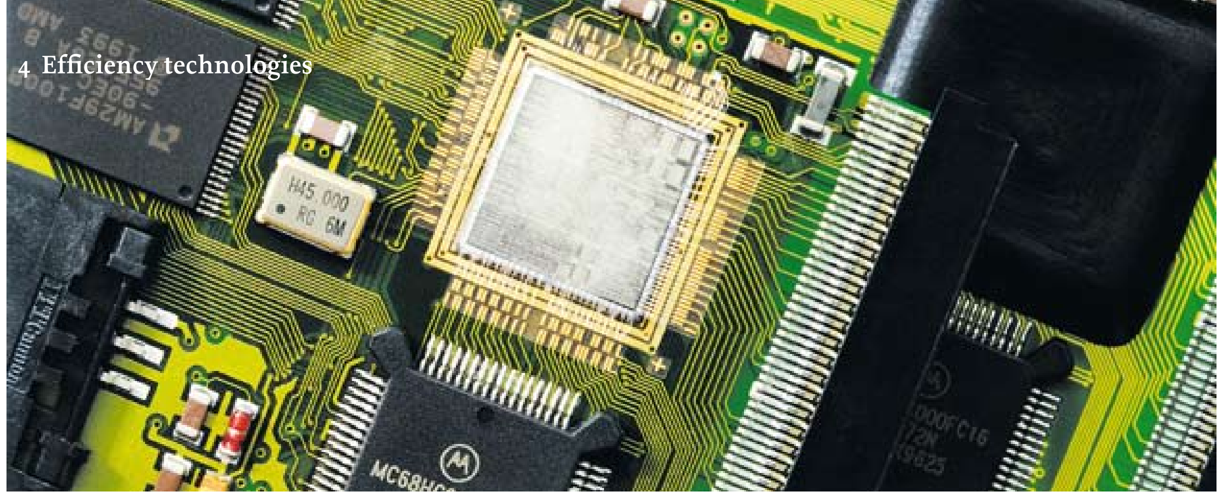
Prof. Dr. Gert Heinrich
Leibniz Institute for Polymer Research Dresden
www.ipfdd.de
gheinrich@ipfdd.de

Energy efficiency and behavior

The social dimension of the rebound effect

A person's energy consumption depends to a large extent on their individual behavior. The aim of a joint project headed by the Centre for European Economic Research and involving the RWI (Rheinisch-Westfälisches Institut für Wirtschaftsforschung) is to study the actual effect of increases in technological efficiency on achieving energy and climate policy goals. Changes in behavior are taken into account, such as the rebound effect which prevents increases in efficiency from being completely translated into energy savings. For example, a new low-consumption automobile will induce the owner to drive more because the higher efficiency makes motoring less expensive. The analysis considers socio-economic factors such as income and education in order to determine the rebound effect.

Dr. Tim Mennel
Centre for European Economic Research (ZEW), Mannheim
www.zew.de
mennel@zew.de



Electronic devices consume electricity but can also be very useful in saving energy.

permanent magnet motors is twice as high. If, in addition, power electronics is used instead of a throttle valve to regulate the rotational speed and adjust the volume flow, the energy losses can be further reduced, in most cases by half.

Electronics is one of the key technologies for efficient energy use, but, by the same token, it can also waste energy. A few years ago many items of electronic equipment consumed around 100 kilowatt hours per year more energy than they do today – even when apparently switched off in standby mode. Today's lower rate of power consumption has been achieved by modifying the component circuitry and incorporating more-efficient microprocessors, storage elements and operation management systems as used in cell phones and laptops.

Mathematical algorithms can be applied to considerably improve the design engineering of industrial plants and processes. And in connection with sensors which monitor the current operating status and transfer this

Urban life consumes vast quantities of energy, a lot of which can be saved by efficiency technologies.

information to a supervisory computer, processes can be run much more closely to their optimal best and production faults prevented – saving energy directly and indirectly.

Sometimes, despite all the efforts, losses of heat cannot be avoided. These can, however, often be re-used. If this is not feasible in the plant causing the wastage, they could be passed on to neighboring plants on an eco-industrial park. If the temperature level is not high enough, this can be raised by means of heat pumps.

If there is no demand for the waste heat it could be converted into electricity, e.g. in thermoelectrical processes. Research work is required here to increase efficiency and reduce costs. The picture is similar for absorption processes which can be used to produce refrigeration using waste heat.

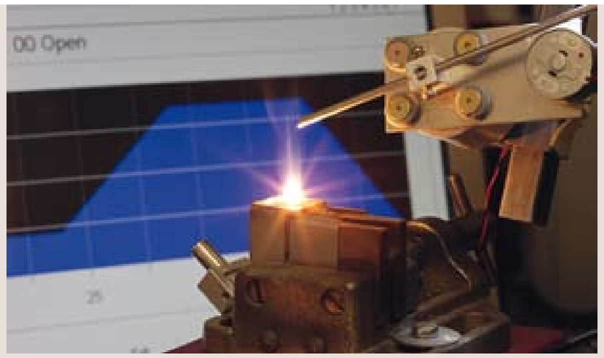
In addition to these cross-sectional technologies which can be used in virtually any industrial operation, further developments or completely new techniques also offer considerable energy-saving potential in many process-

Biogas

Straw power

Biomass contains more energy than can be used during combustion. Research scientists at the Max Planck Institute for Dynamics of Complex Technical Systems have developed a particularly efficient system for producing electricity from biomass. They first generate energy-rich gases such as hydrogen from wood pellets or straw and use it to operate fuel cells. The research scientists have optimized the process to such an extent that they can obtain a usable combustion gas from various types of biomass. As they can use the gas to operate two types of fuel cell, the electrical efficiency of the optimized system can in theory be increased to 50 percent. A conventional biogas plant using a spark ignition gas engine as its generator usually achieves an efficiency of 35 percent.

Prof. Dr.-Ing. Kai Sundmacher
Max Planck Institute for Dynamics of Complex Technical Systems, Magdeburg
www.mpi-magdeburg.mpg.de
sundmacher@mpi-magdeburg.mpg.de

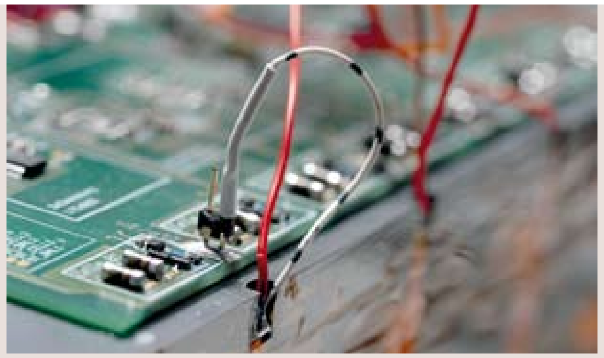


Fuel cells

Efficient power generation

Fuel cells convert chemical energy directly into electrical energy. High-temperature fuel cells, which use hydrogen or natural gas, as well as low-temperature fuel cells, which use hydrogen or methanol, are being developed in Germany. Solid oxide fuel cells (SOFC), which operate at temperatures of 600 °C and higher, are mainly suitable for stationary applications. The aim of current research is to achieve a long service life – 10,000 hours for vehicles and 100,000 hours for stationary power generation – along with high performance and low cost. To this end, work is being conducted on new materials and stack concepts. Simulation models are helping to achieve system efficiencies of over 60 percent.

Dr. Robert Steinberger-Wilckens
Forschungszentrum Jülich in the Helmholtz Association, Institute of Energy and Climate Research
www.fz-juelich.de/ief/ief-pbz/pbzhome
r.steinberger@fz-juelich.de

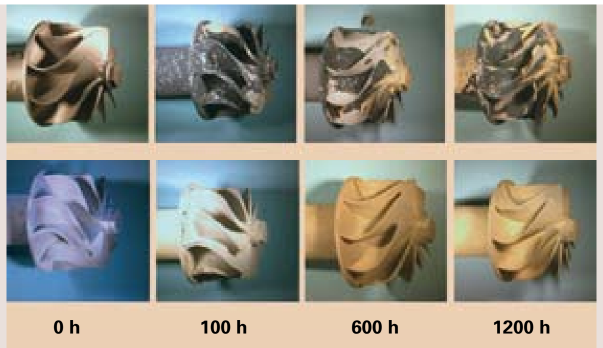


Power electronics

Saving energy with electronics

Electronic systems play a major role in the efficient use of energy. Whether in domestic appliances, entertainment electronics, computers, industrial plants, power supply networks or electric vehicles –controlling energy flows with efficient power electronics can minimize losses and limit a system's electricity consumption to the absolutely essential. In June 2010 the Nuremberg region saw the foundation of the Fraunhofer innovation cluster Electronics for Sustainable Energy Use, which has the remit of strengthening cooperation between companies and research institutes on issues of power electronics and energy technology. The aim is to develop devices and systems which are more reliable and consume less energy.

Prof. Dr. rer. nat. Lothar Frey
Fraunhofer Institute for Integrated Systems and Device Technology IISB
www.iisb.fraunhofer.de
lothar.frey@iisb.fraunhofer.de

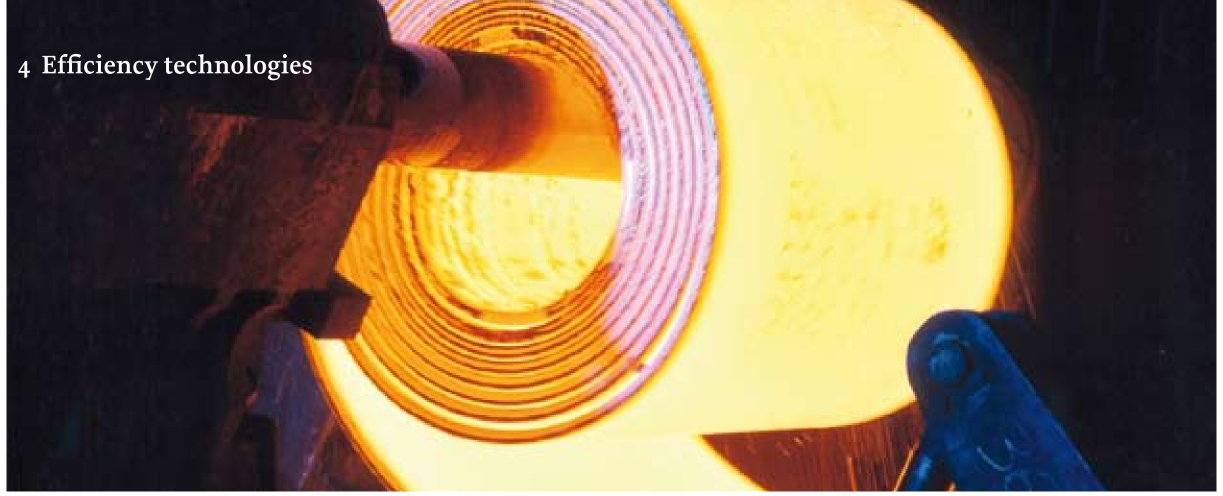


Materials research

Temperature-resistant lightweight construction materials

In the automotive and aerospace industries, as well as in turbine manufacture, lightweight construction alloys based on titanium and aluminum can be used to save weight and fuel. What's more, lighter turbocharger rotors, turbine blades and other components make it possible to attain higher rotational speeds more efficiently. The high temperatures which these components have to withstand are, however, problematic for the use of lightweight construction alloys. A new process makes targeted changes to the surfaces of components of complex shape using ion beams made up of charged particles. This technique is creating new areas of application for lightweight construction alloys in the high temperature range.

Prof. Dr. Andreas Kolitsch
Helmholtz-Zentrum Dresden-Rossendorf (HZDR)
www.hzdr.de
a.kolitsch@hzdr.de



To avoid temperature losses the steel strip is coiled before entering the finishing train.

es. This is the case for sector-specific industrial processes, such as in the production of cement, chlorine, steel and paper, as well as for overarching technologies such as superconductors. These hold great potential as in theory they could be used to transmit electricity without any losses, but fundamental questions of physics need to be answered before superconducting materials can be developed for widespread use in power grids.

Energy system optimization could give rise to further significant energy savings. The aim here is to combine energy sources, supply systems and energy users with each other in such a way that optimum energy efficiency and economy is achieved. For example, in city districts or on industrial parks sources of waste heat could be combined with heat consumers, or various heat applications with decreasing utilization temperatures could be connected together in a cascade to make best-possible use of existing waste heat potential.

Energy-efficient "green" electronics are an increasingly important selling point.

If power/heat cogeneration and renewable energy systems, which entail high investment, are combined with relatively low-cost conventional plants, the economic impact of energy efficiency measures can be considerably increased. In this way energy systems can be realized which are economically competitive, with more than 80 percent of heat demand covered by efficient cogeneration or renewables. The combination of measures on the energy supply side with measures on buildings to reduce the heat required is another area of energy system optimization that holds additional potential for cutting consumption.

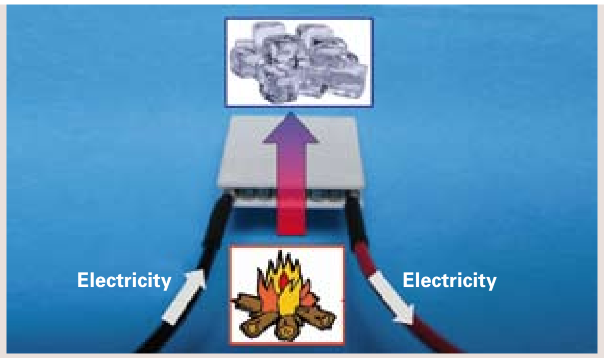
The behavior of consumers as a factor in sustainable energy utilization must not be underestimated. With this in mind, people must be provided with the right equipment as well as proper, easy-to-understand information. Ultimately this will determine whether they are prepared to take responsibility themselves for reducing energy consumption.

Energy-efficient production

Producing more and consuming less

The Green Carbody Technologies InnoCaT innovation alliance set up by equipment manufacturers and suppliers in the auto industry has embarked on the task of conducting research into new technologies, processes and tools for car body production which can be directly implemented in industrial practice. The alliance, which is made up of more than 60 companies, is coordinated by Fraunhofer IWU and Volkswagen AG. Its work focuses on the entire process involved in the production of car bodies, with the aim of reducing the energy consumed by up to 50 percent. This will conserve natural resources and bring down costs and at the same time strengthen the global competitiveness of automotive manufacturers in Germany.

Prof. Dr. Matthias Putz
Fraunhofer Institute for Machine Tools and Forming Technology IWU
www.iwu.fraunhofer.de
matthias.putz@iwu.fraunhofer.de



Thermoelectrics

Nanotechnology turns heat into power

Thermoelectric generators convert heat into electricity without the need for any intermediate mechanical steps. Wherever temperature differences occur, whether just a few or many hundreds of degrees, thermogenerators can be used to produce electricity locally and without emissions. The Nanostructured Thermoelectrics program initiated by the German Research Foundation (DFG) involves 35 working groups across Germany. The challenge for the research scientists is to develop new thermoelectric systems incorporating nanostructured materials which over the long term will be up to 200 percent more efficient than current systems. This would up open up new avenues in energy technology, for instance making it possible to use the waste heat from internal combustion engines.

Prof. Dr. Kornelius Nielsch
Institute for Applied Physics, Hamburg University
www.physik.uni-hamburg.de
knielsch@physik.uni-hamburg.de

Organic LEDs

Plastics with a bright future

Computer and TV screens need to consume less energy, and organic electronics could help. Chemists at the Max Planck Institute for Polymer Research in Mainz have developed fluorescent materials for organic light-emitting diodes. They are easier to make, consume less energy and are more versatile than inorganic LEDs. The research scientists in Mainz have discovered stable substances which emit blue light. Up to now, materials with an adequate service life have not been available for this purpose but they are needed to produce sources for white light. The blue light sources could even be made into films which could be affixed to windows to provide illumination at night and convert sunlight into electricity during the day.

PD Dr. Martin Baumgarten
Max Planck Institute for Polymer Research, Mainz
www.mpip-mainz.mpg.de
baumgart@mpip-mainz.mpg.de

Adaptive surfaces for high-temperature applications

Flow-favorable and self-cleaning

Inorganic materials and their surfaces behave like a "dead" material. In most cases it is not possible to specifically change their properties to match fluctuating loads. As a result, considerable losses can arise in component operation. Under a program involving 13 joint projects across Germany, research is being conducted on material systems and methods which make it possible to optimally adapt material surfaces at high operating temperatures to the surrounding conditions and thus achieve higher efficiency in operation. For example, the manufacturability of flow-favorable self-cleaning surfaces and their resistance to the temperatures arising in a gas turbine are being studied and tested for specific applications.

Prof. Dr.-Ing. Christoph Leyens
Dresden University of Technology, Institute of Materials Science
www.tu-dresden.de
christoph.leyens@tu-dresden.de

Comfort with sustainability

Some 35 percent of final energy currently goes on heating buildings in Germany. For many years though, it has been possible to buy houses that do not require any heating because they lose so little heat that the waste heat produced by the occupants and household appliances, combined with the usage of local renewable energy, provide sufficient sources of heat. In a few years' time, these kinds of "passive houses" will become the norm for supplying residential housing with energy.

Good insulation alone can cut energy consumption drastically.

The challenge faced by research is essentially how to utilize state-of-the-art energy systems more cost-effectively and with the existing building stock, given 80 percent of buildings in Germany are more than 20 to 30 years old. Every upcoming refurbishment project needs to be accompanied by energy-conserving measures based on state-of-the-art technology to ensure that energy and climate-policy objectives can be met, and occupants are still able to afford their heating bills in the future. What is needed are low-cost, robust, durable and architecturally pleasing high-performance insulation systems as well as multifunction facades with adaptive sun protection, daylight usage and energy generation on the part of the building systems. The conversion of final-energy sources into usable energy must also be made more efficient; this includes heat pumps, thermal solar systems and heat storage media, efficient systems for heat recuperation from exhaust air or waste water and, in the broader sense, also systems for the joint provisioning of electricity and useful heat (cogeneration) in the field of advanced building-service installations. Planning tools and building management systems are also important for planning and for building operation. These resources enable such ef-

Consumer behavior

How households decide on their energy mix

In residential households, what factors influence the choice of solution for meeting electricity and heat requirements? An important question that scientists from the Centre for European Economic Research (ZEW) aim to answer. In the seco@home project they are conducting research into consumer behavior regarding energy consumption in residential housing. Using an innovative survey method called conjoint analysis, the researchers aim to find out how such preferences develop in households, what the decision-making basis is and what obstacles prevent the increased usage of sustainable energy sources. The researchers are looking for ways of increasing the proportion of environmentally friendly forms of energy in private households. The project is funded by the German Federal Ministry of Education and Research (BMBF).

Dr. Klaus Rennings
Centre for European Economic Research (ZEW), Mannheim
www.zew.de
rennings@zew.de

Research and information

At the cutting edge of energy research

Whether for heating or cooling buildings, manufacturing industrial goods or operating state-of-the-art communications networks: Energy is the foundation and powerhouse behind modern-day life. BINE Informationsdienst provides practical results from energy research – painstakingly investigated and tailored to specific target groups. Its specialist editorial team comprises experts from engineering and natural science backgrounds who are also excellent journalists. They nurture direct contacts with research institutes and companies that turn efficiency technologies and renewable energy sources into practical applications. BINE Informationsdienst is funded by the German Federal Ministry of Economics and Technology (BMWi).

Dipl.-Biol. Jutta Perl-Mai
BINE Informationsdienst – FIZ Karlsruhe –
Leibniz Institute for Information Infrastructure
www.bine.info
jutta.perl-mai@fiz-karlsruhe.de

The right facade technology ensures a fast return on investment thanks to reduced energy loss.

ficiency technologies to be planned and deployed.

In the case of residential accommodation, the avoidance of heat loss through the facade plays a key role. High-performance insulation systems such as vacuum super insulation and vacuum-insulated glazing, as well as sun protection systems which let through sufficient daylight without dazzling occupants, and facades with integrated photovoltaic or thermal collectors, are key research tasks in this respect. The task of developing practical facades with integrated supply lines and heating surfaces is equally challenging. When these are hung in front of the existing facades when refurbishing old buildings, residents are spared the inconvenience of having to put up with dirt and noise, or even the necessity of having to move out. In many cases, such an approach is needed before a building refurbishment is feasible in the first place. Improved heating systems still need to be developed for cases where buildings cannot be refurbished to passive house standard. Heat pumps fueled by natural gas can substitute condensing boilers over the medium term; micro-cogeneration, e.g. using fuel cells, will provide electricity virtually as a waste product from heat generation for space heating. Phase change materials can store huge amounts of heat despite their low weight – heat that is released during the change from the liquid to the solid phase. This allows the heat of summer days to be pushed into the cool nighttime hours without an air conditioning system. Where this is insufficient, cooling can be generated from solar heat or the waste heat from cogeneration plants or by using switchable natural-gas heat pumps. Or it can be routed from the cool underground to the body of the building and the waste heat from below ground can be reused for heating in the winter with the aid of a heat pump. Excessive solar heat can even be conserved in seasonal heat storage media for the winter. The decisive factor in making these systems worthwhile from an energy standpoint is the size of the heating and cooling surfaces: they must be large enough for the heating or cooling media to only require a minimal temperature difference (LowEx systems).

Building control systems need to be developed into smart home systems so that the complex energy systems of the future can be run optimally, without overtaxing the occupants, while still providing essential functions even when no-one is home.

Harnessing the sun to power buildings should be nothing out of the ordinary nowadays.

Plus-energy schools

Energy waster becomes mini power station

Plus-energy schools are the shape of schools to come. Seen over the year, they generate more primary energy than their operation consumes. To achieve this, the first step in refurbishing a school must be to reduce losses from transmittance and ventilation dramatically. This is accomplished by means of effective thermal insulation of the envelope surface components. The next step is to generate any remaining required energy with minimal losses – where possible using renewable energy sources. A building is only a plus-energy building if it generates this remaining energy requirement itself, for instance by using photovoltaics to produce power from solar energy for its own needs or for feeding into the public grid.

Dipl.-Ing. Hans Erhorn
Fraunhofer Institute for Building Physics IBP
www.ibp.fraunhofer.de
hans.erhorn@ibp.fraunhofer.de

Monitoring systems

Good news for electricity savers

Rising energy prices have led to a boom in efficiency technologies. Fraunhofer researchers have developed a monitoring system that helps keep track of all the electrical appliances in a household, continuously documenting the energy consumption of each device. If consumption increases by an untypical amount, for instance due to limescale buildup in the washing machine or a faulty seal on the fridge door, the system alerts the user and recommends appropriate countermeasures.

Dipl.-Ing. Peter Heusinger
Fraunhofer Institute for Integrated Circuits IIS
www.iis.fraunhofer.de
peter.heusinger@iis.fraunhofer.de

Latent heat stores

Intelligent building materials save energy

Whether you feel comfortable at home largely depends on the ambient temperature. No wonder then that huge amounts of energy are used to keep homes and offices at a pleasant temperature. Modern building materials help save money: Microencapsulated phase change materials can be integrated in building materials which are then capable of storing substantial amounts of heat. Excessive heat during the day can be stored and released at night, without having to switch on the heating. The latent storage materials are a joint development between Fraunhofer researchers and BASF SE.

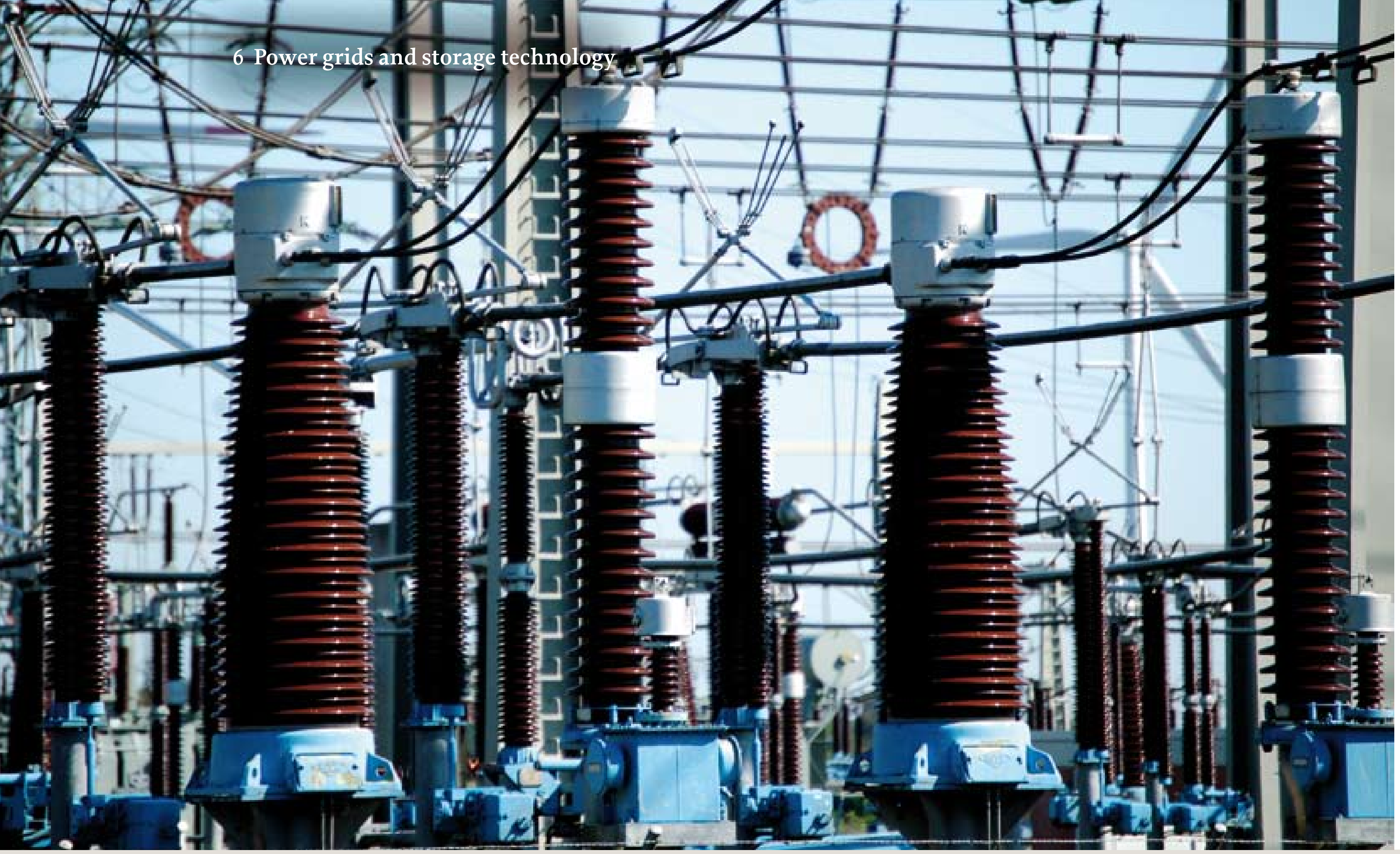
Dr.-Ing. Peter Schossig
Fraunhofer Institute for Solar Energy Systems ISE
www.ise.fraunhofer.de
peter.schossig@ise.fraunhofer.de

Energy-efficient leased accommodation

Incentive to save

Private households account for around a third of annual energy consumption in Germany, with the bulk of energy used for space heating. The authorities provide financial subsidies to improve building energy efficiency – a particularly compelling option if you own the house you live in. In the case of rental accommodation, it is just the tenant that benefits from lower energy costs, with the landlord having no financial incentive to modernize the accommodation’s energy footprint. The resolution of this “investor/user dilemma” is the subject of a research project that is looking at how to provide landlords with a financial incentive to improve building energy efficiency.

Prof. Dr. Manuel Frondel
RWI (Rheinisch-Westfälisches Institut für Wirtschaftsforschung), Essen
www.rwi-essen.de
frondel@rwi-essen.de



Power grids will become crucial in future.

In future, high-voltage direct current transmission (HVDC) will play an important role in transporting power as a cable or overhead line technology. While the technology is in commercial use around the globe and is being developed to support higher voltages and greater distances, there are still no holistic system analyses of large hybrid grid structures made up of DC and AC grids. Yet we can already temporarily increase the transmission capacity of these grids by monitoring the operating states of overhead lines; further optimization of the physical/mathematical modeling and associated integration with holistic grid management are current research topics.

Optimum grid operation calls for control and compensation equipment. Flexible alternating current transmission systems (FACTS) constitute a suitable means of improving the stability and the supply quality of electrical energy supply grids, allowing transmission capacity to be increased by up to 40 percent.

Constant supply security

The increasing reliance on fluctuating renewable energy gives added importance to power grids, flexible generators, load-controlled consumers, and storage technologies. New electricity transmission lines are needed to cope with the widespread regional distribution of locations that generate wind and solar power on the one hand, and consumption hotspots on the other. The time lag between power production and consumption also demands higher energy-storage capacities.

Usage and storage of natural gas

A powder to combat energy wastage

Flaring off natural gas may not be necessary in future. Because chemists from the Max Planck Institutes for Coal Research and of Colloids and Interfaces are using a new catalyst to convert methane, the main component of natural gas, simply and efficiently into easily transportable and storable methanol. This solution proves compelling, particularly where other chemical processes or even a pipeline are uneconomical. At present, oil production worldwide burns off more natural gas every year than Germany consumes. The process can also make sources of natural gas viable that have hitherto been uneconomical. According to current estimates, the resources will last another 130 years – but at present only 60 years' worth of these reserves is economically viable.

Prof. Dr. Ferdi Schüth
Max Planck Institute for Coal Research,
Mülheim an der Ruhr
www.mpi-muelheim.mpg.de
schueth@mpi-muelheim.mpg.de

Storage technology

New reserves for power grids

Renewable energy sources are environmentally friendly, although wind and sun are not available constantly. The power grids will need to be modified accordingly if wind and solar power are to account for a larger portion of overall power consumption. Such changes will entail the need for greater storage capacities. Fraunhofer researchers are primarily focusing on two interesting storage technologies for this application: Redox-flow batteries and compressed air energy storage. Both processes allow energy to be stored long-term and in large quantities, and are therefore ideally suited to smoothing out the fluctuations of renewable energy sources in the power grid.

Dr.-Ing. Christian Dötsch
Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT
www.umsicht.fraunhofer.de
christian.doetsch@umsicht.fraunhofer.de

Electronic electricity meters provide the control centers with important information.

Efficient energy storage: a pumped storage power station.

The future challenges presented by increasingly decentralized and fluctuating energy generation mean medium- and low-voltage grids also need to be included in active grid management. These active grids allow the current state of the grids to be recorded in real time and altered by means of active remote control. In this respect, smart metering constitutes an important component at the low-voltage level. If the control of electrical appliances in households is also included (smart home), along with decentralized flexible energy generators such as cogeneration plants and, in future, fuel cells, the smart grid helps maintain network stability despite a large proportion of fluctuating power stemming from the sun and wind. Until that point is reached, the researchers still have ahead of them some challenging problems to solve and new business models to develop.

However, more storage will also be required if demand is to met by fluctuating power flows from ever less manageable power stations. Virtually the only way large quantities of power can currently be stored is in pump storage power stations, which utilize the height difference between two water basins to store energy. Their potential is geographically limited in Europe, with almost no scope for further expansion. Where the terrain is flat, compressed-air energy storage power stations (CAES) can be used. Here the air is compressed and stored in caverns, and can be vented through turbines as and when required. Current efficiency levels lie between 40 and 50 percent; output power of 100 to 300 megawatts is on tap for one to two hours. The latest research aims to also store the heat generated during compression and utilize this during venting (adiabatic CAES); this increases efficiency to over 70 percent.

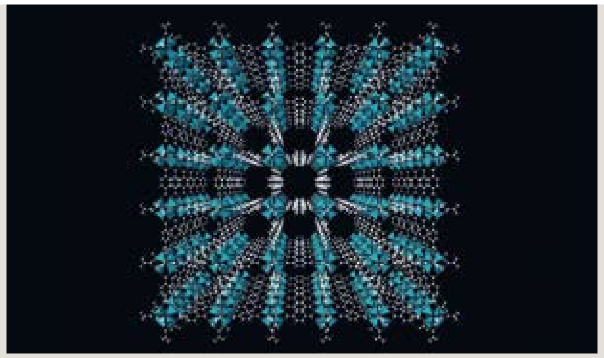
For long-term storage relating to fluctuating renewable energy sources, e.g. to get over week-long lulls in wind and to offset seasonal differences, hydrogen could be used. Once generated, the hydrogen could be stored, in underground rock or salt formations for instance, before being fed back into combined cycle gas turbine plants. Nonetheless, overall efficiency will struggle to exceed 40 percent. Other chemical storage systems

Nanostructured electrodes

New impetus for batteries

Sometimes progress relates to the smallest detail – quite literally in the case of lithium batteries: Scientists from the Max Planck Institute for Solid State Research are honing the batteries with nanotechnology for use in electric cars. Nanostructured electrodes provide high storage capacity coupled with fast charging and discharging. The batteries can also be charged faster if the researchers mix nanoscopic silicon dioxide particles – basically tiny grains of sand – in with the electrolytes. Ions wander to and fro between the poles in the battery through the electrolyte. The silicon dioxide separates negative and positive ions, thereby increasing the conductivity. This approach also makes the batteries sturdier and less inflammable.

Prof. Dr. Joachim Maier
Max Planck Institute for Solid State Research, Stuttgart
www.fkf.mpg.de
s.weiglein@fkf.mpg.de

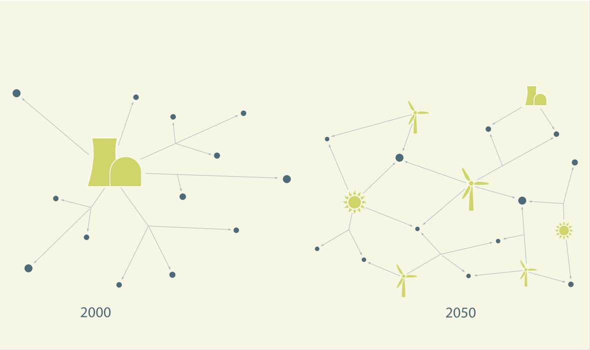


Hydrogen technology

Space sensation in your fuel tank

Hydrogen is a fuel with a bright future. Yet the issue of efficient storage still remains unresolved. For a fuel cell-powered car to travel 500 kilometers, it must store hydrogen at a pressure of 700 atmospheres in a gas tank – by no means a simple task. Storing the hydrogen in a solid dramatically reduces the pressure and, in turn, the cost. Scientists from the Max Planck Institute for Metals Research are conducting research into metal organic frameworks (MOFs). These are extremely porous and have an internal surface area of 4000 m^2 per gram – more than half a soccer pitch. While these new materials already offer hydrogen lots of space, the properties now need to be optimized for a hydrogen tank in a car.

Dr. Michael Hirscher
Max Planck Institute for Metals Research, Stuttgart
www.mf.mpg.de
hirscher@mf.mpg.de

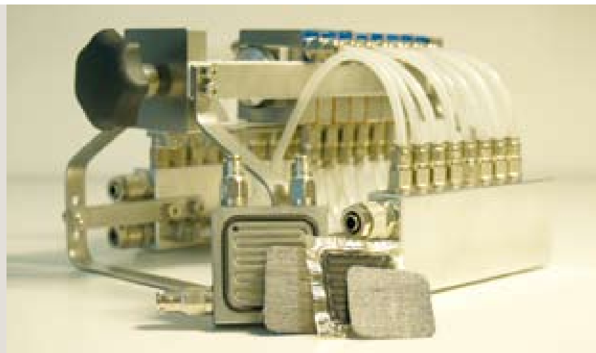


Power grids

Built-in fault tolerance

Our power grids are set to change radically over the next few decades. The handful of large power stations will be replaced by a host of small suppliers that generate power from renewable energy sources. What form will that grid take – a grid that is decentralized and yet resilient enough to withstand faults and supply fluctuations? Max Planck scientists in Göttingen are looking into these questions, drawing inspiration from methods normally used to describe processes such as the interaction of nerve cell networks in the brain. The aim is to understand how dynamically changing power grids can organize themselves. This know-how can then be used in order to plan and operate the grids so they need minimal control from outside.

Prof. Dr. Marc Timme
Max Planck Institute for Dynamics and Self-Organization, Göttingen
www.nld.ds.mpg.de
timme@nld.ds.mpg.de



Power generation

New membranes for fuel cells

The fuel cell is regarded as the environmentally friendly energy source of the future, whether as a power source for the electric car, or to provide power and heat in the home. At its heart is the membrane that conducts protons. This membrane has to be sufficiently conductive across a wide temperature range and with relative humidity of less than 90 percent. Operating temperatures in excess of 100 °C simplify water management, cooling and reduce catalyst usage. The membrane working group at the Leibniz Institute of Polymer Research Dresden has teamed up with the University of Stuttgart (ICVT) to develop suitable membranes based on wholly aromatic polymers, paving the way for the widespread usage of the fuel cell.

Dr. Jochen Meier-Haack
Leibniz Institute of Polymer Research Dresden
www.ipfdd.de
mhaack@ipfdd.de

Research into new lithium-ion batteries should further increase the potential energy density of the electricity storage devices.

could also be considered; their suitability needs to be analyzed from a holistic system viewpoint.

Redox-flow batteries could achieve around 75 percent efficiency, since they store energy chemically without any losses. This technology is ideally suited to large storage capacities, for instance at grid nodes, because energy storage takes place separately from the conversion, in liquid electrolytes that are stored in conventional tanks. Lithium-ion batteries are the most promising battery technology at present. They are set to become more commonplace in areas such as electromobility, smaller decentralized grid storage devices as well as in making renewable energy sources more practicable. For this to happen, however, further work will have to be done on safety aspects, and the batteries' storage-specific cost will have to come down. Compared with other battery storage technologies these costs are still very high at 500 to 1000 euros per kilowatt hour.

Better energy grids will also ensure reliability and comfort in future.

In many cases it will be more cost-efficient to shift the power demand to periods where sufficient electricity is available. This is fairly easy to do wherever energy-intensive processes can be time-shifted on an industrial scale. Suitable processes include large groundwater pumps or central frozen-storage facilities. Even in the private sector, load can be managed to a certain extent. Freezer cabinets and other applications that tend not to be time-critical can be briefly switched off or delayed in high-load periods; these kinds of applications can be controlled via price signals or by means of centralized instrumentation and control.

Even shifting the cool of the night into the afternoon period can reduce the usage of air conditioning systems. Here research is focusing on phase change materials that boast a high storage capability.

Supply concept

Grid for electricity from renewable sources

It can be done: Germany could essentially meet its entire electricity needs using renewable sources. This is the conclusion drawn by the Kassel-based researchers led by Dr. Kurt Rohrig in their calculations as part of the "Renewable Combined Cycle Power Station" pilot project. They combine the various characteristics of solar, hydro, wind and biogas power stations with a pump storage station. The scientists have managed to control and coordinate exactly the various power sources to meet demand precisely and reliably, thereby ensuring a consistent, reliable energy supply based solely on renewable energy sources. Dr. Rohrig received the German Climate Protection Prize 2009 for his concept.

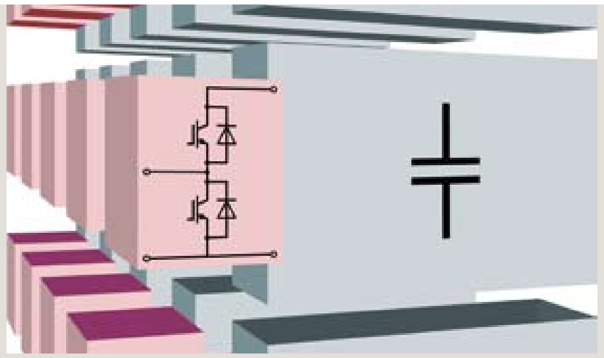
Dr. Kurt Rohrig
Fraunhofer Institute for Wind Energy and Energy System Technology IWES
www.iwes.fraunhofer.de
kurt.rohrig@iwes.fraunhofer.de

Energy storage devices

Hydrogen is the future

Rostock-based researchers are looking into hydrogen storage, e.g. for fuel cells. 5 milligrams of the ruthenium catalyst developed at the Leibniz Institute for Catalysis (LIKAT) generate 125 liters of gaseous hydrogen from 233 milliliters of formic acid. The LIKAT researchers are also looking into the viability of converting the released carbon dioxide back into formic acid, using hydrogen from renewable raw materials. What you end up with is a closed loop: Formic acid can store hydrogen in a CO_2-neutral manner and is nonpoisonous and easy to handle. In the foreseeable future, the catalytic generation of hydrogen for fuel cells will be feasible in laptops. In the long term, cars could even be powered using this principle of generating electricity.

Prof. Dr. Matthias Beller
Leibniz Institute for Catalysis (LIKAT)
www.catalysis.de
matthias.beller@catalysis.de

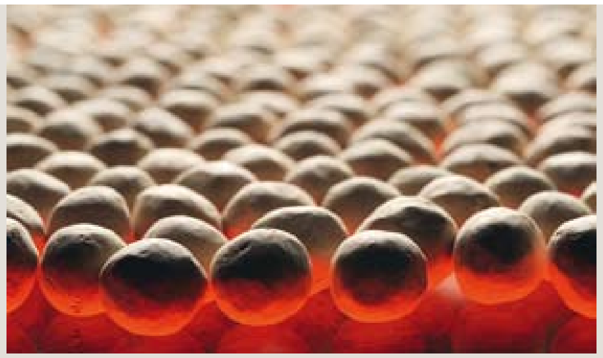


Energy electronics

Switchgear cells for the power grid of the future

Renewable energy sources are playing an increasingly important role. Plant and components for power transmission must be tailored to the future energy mix so that electrical energy reaches the consumer with minimal losses and reliably. One example is high-voltage direct current transmission from offshore wind parks. Fraunhofer researchers are developing high-power switches, switching topologies and systems that boast superb efficiency and reliability, optimized damage protection, compact design, scalability and cost-effectiveness. Thanks to flexibility and adaptability to specific usage conditions, the technology can be applied in other fields such as railway networks or large industrial plant.

Dipl.-Ing. Markus Billmann
Fraunhofer Institute for Integrated Systems and Device Technology IISB
www.iisb.fraunhofer.de
markus.billmann@iisb.fraunhofer.de



Heat storage

Hot stuff

Valuable high-temperature heat which is surplus to requirements is often available in industrial processes and in solar thermal power plants. Wouldn't it be good to develop versatile thermal energy storage devices to store this surplus energy for use as and when required? As a result, cyclical industrial processes could be run using less power, solar thermal power stations could also provide power or process heat after the sun has gone down, or conventional cogeneration plants could be operated to a flexible timetable. Together with industry partners, the German Aerospace Center (DLR) is developing innovative, low-cost high-temperature solid and latent heat storage media and thermochemical storage devices for the range of 100 to 1000 °C.

Dr. Rainer Tamme
German Aerospace Center, member of the Helmholtz Association, Institute of Technical Thermodynamics
www.dlr.de
rainer.tamme@dlr.de

Storing sufficient electricity in the car poses a very complicated technical challenge.

Certain challenges still need to be resolved before electric cars can be rolled out universally in the marketplace, especially in relation to the development of key technologies. First of all there is the lithium-ion battery, which needs to be improved substantially in terms of costs, energy density, weight, cyclical and calendrical service life and charge speed if it is to compete with conventional vehicles. Efficient production plants also need to be developed for vehicle batteries to reduce costs and deliver the necessary volumes. With around 70 percent of value creation for the battery relating to the battery cell, cell production in Germany is an important issue; German companies in this segment still lag a fair way behind other international competitors. Battery modules and systems are equally important research topics.

Longer term, there is the need to develop and roll out the recycling of vehicle batteries – not least with regard to raw materials, including lithium, cobalt and

Smoothly and cleanly in motion

Wildly fluctuating oil prices have added weight to the debate surrounding electromobility over the past few years. Political objectives such as reducing dependency on oil, more efficient energy conversion, substantial CO_2 reduction and reduced local traffic emissions are, alongside industrial policy objectives such as the significance of the automotive sector in Germany, important arguments in favor of electromobility. This is why the federal government's Coalition Agreement sets out the objectives of developing "Germany into the lead market for electromobility by 2020" and getting "One million electric vehicles by 2020" onto the country's roads.

Battery technology
More power on the road

Modern electric vehicles already use lithium-ion batteries to store energy, but further significant increases in performance to enhance range will be required before this type of battery can become a low-cost mass product. A program run by the German Research Foundation (DFG) is investigating and optimizing specially designed materials for enhanced lithium-ion batteries. More than thirty research groups at universities and extra-university institutions have joined forces to improve battery output and safety to meet future needs.

Prof. Dr. Hans Jürgen Seifert
TU Bergakademie Freiberg, Institute of Materials Science
http://tu-freiberg.de/fakult5/iww
seifert@ww.tu-freiberg.de

Traffic systems engineering
AutoTram should fill the gap

Local public transportation makes a major contribution to meeting people's mobility requirements. Heavily used routes are predominantly served by rail-based systems which unfortunately require high levels of capital expenditure and are inflexible when it comes to routing. By contrast, capacity quickly becomes an issue with buses. The AutoTram concept combines the best of both worlds and also features highly efficient electric drive motors coupled with high-power batteries and supercaps. The result is low-emission transportation. The AutoTram is being used in Dresden, as part of the "Entrepreneurial Regions" program – funded by the German Federal Ministry of Education and Research (BMBF).

Dr. Jan Schubert
Fraunhofer Institute for Transportation and Infrastructure Systems IVI
www.autotram.net
jan.schubert@ivi.fraunhofer.de

Electric cars can match the performance of other vehicles.

manganese. Owing to their higher energy density, next-generation batteries, such as lithium-sulfur, metal-air or redox-flow batteries, ought to make the transition from basic research to practical applications.

Electric motors which can provide sufficient power for motor vehicles must also be developed and produced in a low-cost way, as must the associated power electronics. To improve efficiency, the issue of heat and cooling management in electric vehicles must be tackled. Starting points in this respect could be in the preconditioning or the development of new vehicle concepts with a focus on insulation and driving space design. In general, it must be emphasized that there are still only a handful of integrated vehicle concepts tailored to electric vehicles, with significant development potential in this area.

The vehicle connector also offers major scope for improvement. Issues include the development of low-

New mobility concepts need to appeal to users.

cost power charging systems for the home or in the semi-public arena. Work also needs to be started on developing effective fast-charging systems that can deliver an output of over 100 kilowatts. IT solutions need to be developed to provide a connection to the power grid and better integration of fluctuating renewable and decentralized power generation units. Smart grids offer a suitable platform for electric vehicles. One important issue that needs to be addressed in rising to these challenges involves the development of new mobility concepts. These concepts should look not only at the possibilities and limits of electric vehicles but also at user acceptance and how to influence it. Notable options in this respect include car sharing or car-to-go concepts, as well as linking electric vehicles to public transport.

Electromobility System Research

A system for mobility

Electromobility needs to be systematically promoted in Germany to ensure the auto industry, along with power generation and storage, remain competitive and the country remains a key player in shaping international development. As part of the "Electromobility System Research" project, Fraunhofer intends to support the transition to a sustainable all-electric economy. This approach stands apart with its focus on coordinating research into all the value-creation stages of electromobility – from power generation, through transmission and distribution of energy via the power grids, the interfaces between power grid and vehicle, energy storage, through to new vehicle concepts with a new infrastructure, as well as usage and billing concepts.

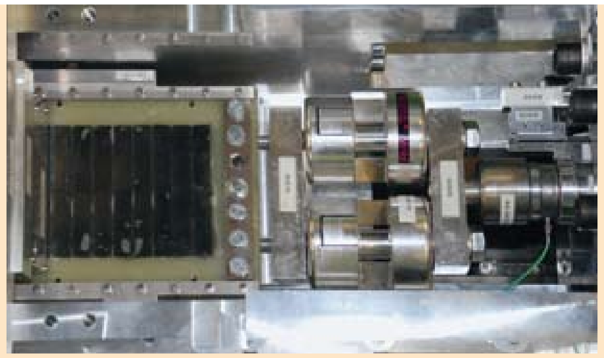
Prof. Dr.- Ing. Holger Hanselka
Lead Coordinator Electromobility System Research
Fraunhofer Institute for Structural Durability and System Reliability LBF
www.lbf.fraunhofer.de
holger.hanselka@lbf.fraunhofer.de

Acceptance research

User-friendly electromobility

Electromobility is set to become the mainstay of urban traffic in the future. It can contribute to reducing dependency on fossil fuels. The technical prerequisites as well as user acceptance are crucial to the successful establishment of electromobility. Interest focuses, for instance, on how drivers deal with the charging process and the limited range of the vehicles. Researchers from the TU Berlin are looking into the current and future requirements of electric-vehicle users and drawing up, in cooperation with the TU Dortmund, an infrastructure plan for charging locations into which the results of the user analysis will be integrated. In this the researchers are aiming to create the ideal conditions for the widest possible usage of the electric drive.

Prof. Dr.-Ing. Christine Ahrend
Technische Universität Berlin,
Institute of Land and Sea Transport Systems
www.ils.tu-berlin.de
christine.ahrend@tu-berlin.de



Free-piston linear generator

Range extender just in case

Despite the expected increase in energy and power density of batteries, the range of battery-electric vehicles will remain limited. Auxiliary motors, so-called range extenders, can increase the range, but more research is still needed. A range extender has to be light, compact and easily integrated into the vehicle. It also has to kick in smoothly. The German Aerospace Center (DLR) is developing the free piston linear alternator – a range extender that precisely meets these requirements. What is more, its variable compression and stroke give rise to high efficiency with low emissions, enabling the range extender to be powered with various fuels. Its ultraflat design also makes it easy to position the unit optimally in the vehicle.

Dr.-Ing. Christian Piehler
German Aerospace Center, member of the Helmholtz Association, Program Directorate Transport, Cologne
www.dlr.de
christian.piehler@dlr.de

Sustainable mobility

Research into mobility's consequences

Sustainability in the transport sector covers various aspects. Emissions and the energy sources and drive technologies used all play a role, but so do social costs due to traffic jams, accidents, environmental damage, noise and climate change. Empirical findings on accessibility and social participation, on the consequences of regional developments such as suburbanization and urban sprawl as well as the financing of transport must be taken into account. On the other hand, sustainability also involves analyzing various regulatory and pricing policy measures such as road tolls and emissions trading, as well as the role of technical innovations and technical norms, such as emissions standards.

Prof. Dr. Claudia Kemfert
German Institute for Economic Research,
Energy, Transportation, Environment Research Department
www.diw.de
ckemfert@diw.de

Sustainable and inexhaustible

Compared with other sources of energy supply, renewable energy boasts some compelling advantages: It is potentially inexhaustible, since even thousands of years from now the wind will still be blowing, water will be flowing, and the sun will shine forever from a human point of view. The technologies used are also fairly simple so that essentially they are available to everyone. Furthermore, the use of these energy sources generates on balance virtually no additional CO_2. Nonetheless, a great deal of research still needs to be done on the detail.

Solar cell researchers are making modules increasingly efficient.

Solar energy

The sun provides a virtually unlimited energy source. The Earth's population currently needs 15 terawatts of power in total, but the solar radiation that reaches Earth on a continuous basis amounts to 120,000 terawatts. Just a fraction of this power would therefore cover the bulk of our energy requirements. Solar energy can be used in buildings by employing structural measures or by fitting solar collectors and photovoltaic modules. Photovoltaics (PV) have been experiencing a boom for several years – on the back of a range of incentive programs. The global installed peak power has grown to over 30 gigawatts. A viable industry has developed around solar energy, which generates jobs while dramatically reducing the associated production costs. Solar power in Germany may well be cheaper than household electricity by the middle of the decade.

Well over 80 percent of solar cell capacity manufactured to date is based on crystalline silicon. This type of solar cell's efficiency, value for money, long-term

Solar cell research
High-power cells and concentrator technology

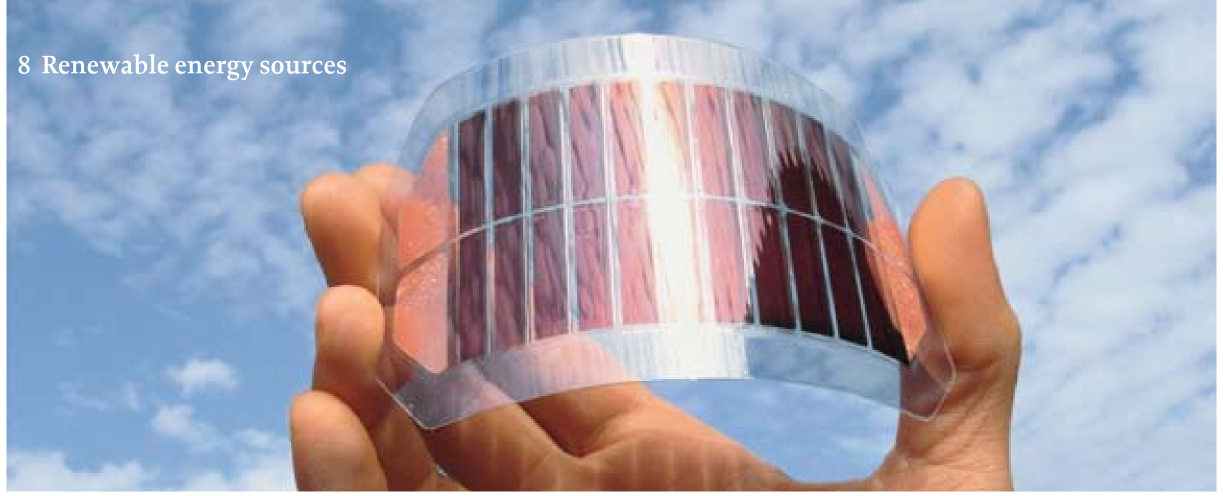
Researchers at Fraunhofer ISE are continually optimizing cell concepts, production processes and module technologies for the silicon technology that dominates the market. They hold the world record (20.4 percent) for the efficiency of conventional solar cells based on multicrystalline silicon. A new solar-cell concept also allowed them to push efficiency to a record 41.1 percent: Three solar cells are connected in series so that the solar spectrum can be converted very efficiently. The multiple solar cells measuring a few square millimeters are located at the focal point of a lens which concentrates the sunlight up to 500 times. Concentrix Solar GmbH is marketing the material-saving design in the form of FLATCON® modules.

Prof. Dr. Eicke R. Weber
Fraunhofer Energy Alliance spokesman
Fraunhofer Institute for Solar Energy Systems ISE
www.ise.fraunhofer.de
eicke.weber@ise.fraunhofer.de

Solar thermal power stations
Concentrated sun power

Concentrating solar systems work on the same principle as magnifying glasses: They focus solar radiation to generate heat, with temperatures reaching from 150 °C to over 3000 °C. At these temperatures, the solar thermal energy can be used in a variety of ways: to generate electricity, for direct use in technical processes or to produce fuels. Solar thermal power stations can also generate low-cost electricity after sundown, as heat can be stored more efficiently than mechanical or electrical energy. The German Aerospace Center (DLR) is collaborating with other partners to optimize solar systems. The aim is to boost efficiency and thus reduce costs by increasing today's process temperatures of around 400 °C to over 1000 °C.

Prof. Dr. Robert Pitz-Paal
German Aerospace Center, member of the Helmholtz Association,
Institute of Technical Thermodynamics
www.dlr.de/tt
robert.pitz-paal@dlr.de



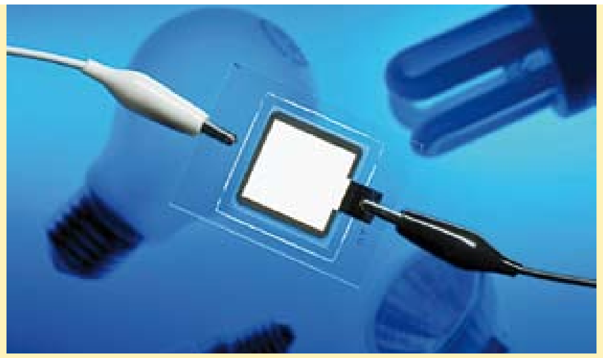
Organic solar cells are low-cost and can be used everywhere.

Locations with high levels of solar radiation are ideal for solar power stations.

stability and cost-reduction potential mean it is likely to remain the market leader in the terrestrial photovoltaics segment, but the market share of PV thin-film modules is growing. These are generally made using amorphous and microcrystalline silicon (a-Si, µc-Si), cadmium telluride (CdTe) or copper indium (gallium) sulfur-selenide compounds, the so-called CI(G)S solar cells. Ultraefficient multiple solar cells made up of III-V semiconductors have been producing power in space for many years; they are increasingly also being used terrestrially as concentrating PV systems (CPV). Dye-sensitized and organic solar cells have also made substantial progress; they boast very low manufacturing costs and cover wide-ranging applications. Along similar lines to PV modules, the output and production costs of converters – a key element in PV modules – could be improved substantially.

Solar thermal systems are used in building systems, in industry or as outdoor facilities. Solar generated heat can be used directly, transformed into cold using refrigeration machinery or converted into electricity using heat engines. Solar thermal collectors and systems with flat and vacuum tube collectors are currently operating in process water and solar heating facilities, in cooling and air conditioning plants and in seawater desalination plants. Collectors built into facades and window collectors are also in use. Linear concentrating collectors can reach operating temperatures of over 400 °C. Both solar tower power stations as well as trough and Fresnel collectors provide solar thermal power supply for large power stations, as well as for generating process heat, process steam and driving heat for absorption refrigeration systems.

In countries with large amounts of direct solar radiation, solar thermal power plants offer huge potential for the cost-effective generation of solar power to cover daily peak requirements and the base load. They generate steam that drives a turbine, as in a conventional power station. Consequently, solar fields can also be easily integrated into hybrid power stations. Hybridization or thermal storage means these power stations can also supply electricity at night.

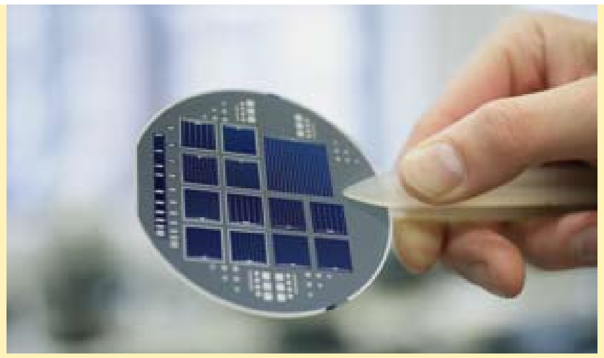


Organic solar cells

Low-cost solar energy

Organic semiconductors are made of hydrocarbons – compounds that have been used for many years in various products, for instance pigments in paints. Applied as an ultrathin layer, they allow flexible solar cells to be constructed at relatively low cost. Furthermore, these cells can also be designed to be transparent or have attractive colors, making them ideally suited for eye-catching integration into facades. Current research is focusing on increasing their efficiency and service life, which are insufficient at present. The German Research Foundation (DFG) has set up a program with more than 30 working groups pooling their resources to tackle this interdisciplinary issue.

Prof. Dr. Karl Leo
Dresden University of Technology, Institute of Applied Photo Physics
www.iapp.de
karl.leo@iapp.de

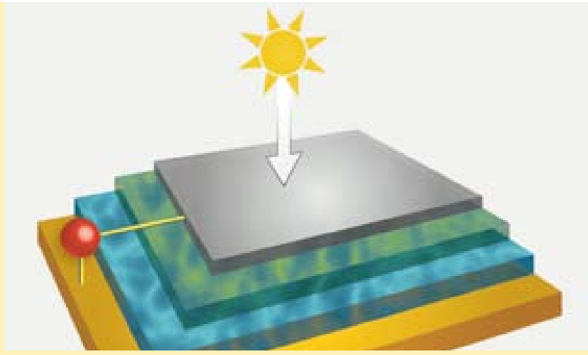


Solar cells

Silicon on glass – wafer-thin

Silicon solar cells – produced from single crystals (wafers) – currently dominate the market. To reduce the high cost of materials, researchers from the Helmholtz-Zentrum Berlin für Materialien und Energie are trying to apply silicon in ultra-thin layers onto glass – an extremely difficult feat. The semiconductor grows polycrystalline, i.e., in a large number of small crystals, and charge carriers are lost at every crystal boundary. The researchers want to circumvent this drawback using e-beam evaporation: They deposit the silicon amorphously, in other words in non-crystalline form, and let it anneal at 600 °C. This produces well structured crystals that are now a few micrometers in size.

Prof. Dr. Bernd Rech
Helmholtz-Zentrum Berlin für Materialien und Energie, Institute for Silicon Photovoltaics
www.helmholtz-berlin.de
bernd.rech@helmholtz-berlin.de

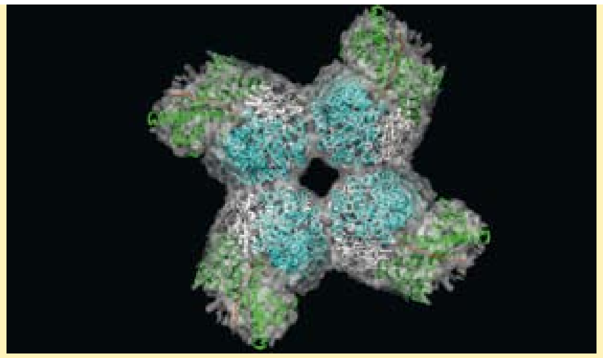


Solar cell research

A window for solar energy

Graphene could eliminate an impending bottleneck affecting the production of solar cells. Max Planck chemists have a simple, reliable process for manufacturing films of the material, which is composed of individual layers or at most a few layers of carbon atoms. These films could be used in future as window electrodes for solar cells, providing a potential replacement for indium-tin oxide, which is starting to run out. Window electrodes coat the silicon and must let the sunlight pass through for it to produce free electric charge in the semiconductor. The electrodes bleed off this charge as electricity. Graphene electrodes would make solar cells even more efficient: Unlike indium-tin oxide, they also allow infrared sunlight – which accounts for around half of solar radiation – to pass through.

Prof. Dr. Klaus Müllen
Max Planck Institute for Polymer Research, Mainz
www.mpip-mainz.mpg.de
muellen@mpip-mainz.mpg.de



Photosynthesis

In nature's power station

It is something only nature has been able to do thus far: Plants or photosynthetic bacteria utilize the energy of sunlight to generate chemical energy sources such as sugar or hydrogen directly. Yet the sophisticated mechanism of photosynthesis is not very efficient. To remedy these shortcomings, Max Planck researchers are investigating the process and all the components involved in it down to the smallest detail. Researchers from the Max Planck Institute of Biochemistry have now managed to explain how plants produce the enzyme Rubisco. Rubisco binds carbon dioxide and triggers its conversion into sugar and oxygen, albeit not very effectively. Since the researchers now understand how it is made, they can alter specific variables to produce more efficient variants of the enzyme.

Prof. Dr. Franz-Ulrich Hartl
Max Planck Institute of Biochemistry, Martinsried
www.biochem.mpg.de
obermayr@biochem.mpg.de

Wind power ranks among the most important renewable energy sources.

Offshore wind turbines are extremely efficient, but cost more to maintain.

Wind power

Wind power has become a significant economic factor and will also provide a substantial proportion of renewable energy sources in the energy mix of the future. Wind turbines accounted for 39 percent of the EU's new power station capacity installed in 2009, with more than 10,000 megawatts of additional wind power connected to the grid that year.

The pace of innovation in the market is staggering. At present, turbine designs with outputs between 750 kilowatts to 3 megawatts have become the preferred option on land. The trend is toward larger rotor diameters with the same output in order to obtain sufficient yield in low-wind locations. Mass production is on the rise, and this will further reduce prices for the favored models. Owing to higher average wind speeds, offshore wind turbines hold the promise of higher energy yields. However, higher dynamic loads are also exerted on the turbines in these locations: The stresses arising from turbine operation, wind and waves combine with environmental factors to impact on the structures and accelerate aging and wear.

Offshore wind turbines have to be extremely reliable, and this is a major challenge for the R&D engineers. Reliability is the prerequisite for high system availability, low maintenance overheads and minimal downtime – a formula that adds up to more cost-effective turbine operation. There is also substantial research potential as regards rotor blade profiling, the impact of the wind on the turbine and the interaction between several wind turbines in succession.

Offshore wind parks

Reliability at sea

The RAVE research initiative is following the construction and operation of the "alpha ventus" test site, which aims to provide broad-based experience and knowledge for future offshore wind parks. The turbines are fitted with a wide range of additional metrology so that RAVE can provide all the project partners involved with detailed data. RAVE is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and coordinated by the Fraunhofer Institute for Wind Energy and Energy System Technology IWES. The 15 joint projects currently underway are supported by turbine manufacturers and several research institutes that are involved in the initiative.

Dr. Bernhard Lange
Fraunhofer Institute for Wind Energy and Energy System Technology IWES
www.iwes.fraunhofer.de
info@rave-offshore.de

Wind energy research

Berlin backs wind energy

Wind energy of the future requires unwavering support from research. Scientists from the Technische Universität Berlin are working on new aerodynamic concepts for very large and very small wind turbines. A large number of technical problems need to be overcome before these turbines can be implemented, from robust support structures for offshore turbines, automated production and testing, safe transportation and environmentally friendly assembly, through to distance monitoring and fault-free operation over many years. These ambitious objectives are being implemented in scientific and technological projects together with the German Federal Institute for Materials Research and Testing, and industry partners in the new WIB (competence center wind energy Berlin).

Prof. Dr. Yuri Petryna
Technische Universität Berlin,
Kompetenzzentrum Windenergie Berlin WIB
www.wib.tu-berlin.de
yuriy.petryna@tu-berlin.de

Postgraduate Programme Renewable Energy

Vocational training in renewable energy

Renewable energy sources are a promising research and work field. Back in 1987, the DAAD set up the "Postgraduate Programme Renewable Energy (PPRE)". The course, which runs over three semesters, provides graduates that already have professional experience in the field of "energy" with insights into the theory and application of renewable energy sources, allows them to check their skills in the lab or as part of outdoor experiments, visit companies and gain vocational training in industry or research institutions. Graduates completing the course often find employment in industry, with consulting firms, NGOs or in research institutions around the world.

Anke Stahl
German Academic Exchange Service (DAAD)
www.daad.de
stahl@daad.de

Research grants

Humboldt supports material scientists from emerging countries

Materials research is an innovation driver – especially for the development of new energy sources. From 2010, the Alexander von Humboldt Foundation will each year be offering 30 Humboldt research grants for scientists doing research in the field of material sciences, especially in applications with societal relevance, such as environmental protection and environmentally friendly energy supply. The grants aim to support cooperation with researchers from key emerging countries. Annually, the Humboldt Foundation enables over 2000 scientists from around the world to conduct research in Germany. The Foundation maintains a global network of more than 24,000 Humboldt scientists in all disciplines in over 130 countries.

Dr. Johannes Belz
Alexander von Humboldt Foundation
www.humboldt-foundation.de
johannes.belz@avh.de

Energy from biomass only releases as much CO_2 as the plants have previously absorbed from the atmosphere.

Forests are natural CO_2 stores.

Biomass

The use of fossil fuels and the current reduction of photosynthesis capacity due to large-scale deforestation push up the amount of CO_2 in the atmosphere – which in turn promotes climate change. The transition to a sustainable energy supply in which no additional CO_2 is released is therefore one of the key challenges for the 21st century. The use of renewable biomass, which contains a large proportion of water, plays a prominent role in obtaining bioenergy – in the form of biomethane or fuels, for instance. Unlike combustion, which requires the biomass to undergo a previous drying stage, biogas can be obtained from the aqueous phase without an external energy source. This means a large amount of usable energy can in principle be obtained by this process.

Current research is looking at how to convert the biomass as efficiently as possible. Leftover biomass that is largely lignin-free is ideal for this since it can be obtained cheaply and without high transportation costs.

In many regions, putting out waste biomass as part of refuse collection is already prohibited; alternative disposal by drying and combustion entails far higher costs. The focus of the technical development work is on decentralized, substrate-specific plants which allow the energy inherent in the biomass to be utilized near to the point of production. This obviates the need for energy-hungry transportation and translates into a higher energy yield.

Numerous researchers are working on converting biomass containing lignin, such as waste wood and straw, into usable energy or transportable liquid energy sources. This would mean that agricultural land could be managed optimally and competition with food production avoided. To the same end, traditional and biotechnology methods are being used to grow plants which bind carbon dioxide more efficiently in the biomass. This allows more biomass to be produced in less time on a given area.

Reduction of CO_2
Biogas and biocoal open up the carbon sink

The untapped potential for producing biogas is still enormous. Organic waste, in particular, could be used more efficiently. At the Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB) a group of researchers is developing an energy-efficient hybrid process which combines biogas fermentation to produce methane with thermochemical carbonization of the fermentation residues to create biocoal. The core technology is the upflow process developed at the ATB. Only waste materials are used, predominantly those with a high-fiber content such as straw, grass or solid manure. The biocoal is not meant to be burned but used as a soil conditioner. It can also bind carbon long-term in the ground – a contribution to permanently removing CO_2 from the atmosphere.

Dr. Jan Mumme
Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB)
www.atb-potsdam.de
jmumme@atb-potsdam.de

Biofuel
Wood in the tank

Fuels made from renewable raw materials are a fantastic idea – provided agriculture can still produce sufficient food. Chemists from the Max Planck Institute for Coal Research are helping to defuse this rivalry. They have developed a viable method of converting agricultural and forestry waste into biofuel. Initially, the researchers dissolve straw or wood waste in an ionic fluid, thus softening the cellulose, the main component of plants that is difficult to digest even for microorganisms. Next they split the long sugar chains into shorter snippets with an easy-to-use catalyst. These can in turn be broken down into sugar using established methods; the sugar is then fermented to create ethanol.

Prof. Dr. Ferdi Schüth
Max Planck Institute for Coal Research, Mülheim an der Ruhr
www.mpi-muelheim.mpg.de
schueth@mpi-muelheim.mpg.de

Biofuels
Sustainable mobility with biomass

Fuels obtained from biomass, when used in mobile applications, have substantial potential not only for reducing carbon dioxide emissions that affect the climate but also for significantly cutting engine pollutant emissions such as soot or nitrogen oxides. Scientists in the "Tailor-Made Fuels from Biomass" Cluster of Excellence are conducting research into the production and in-engine combustion of innovative biofuels. The long-term goal is to optimize the entire process chain from biomass through to the internal combustion engine, wherever possible without competing with the food chain. In this way, the researchers aim to make an important contribution to the sustainable mobility of the future.

Prof. Stefan Pischinger
Institute for Combustion Engines, RWTH Aachen University, JARA Energy
www.fuelcenter.rwth-aachen.de
office@vka.rwth-aachen.de

Biomass as a renewable carbon source
Synthetic chemical products and fuels from biomass

The bioliq® process transforms dry biomass into high-grade, liquid synthetic fuels and basic chemical products. Power and heat are generated as byproducts and are used to cover the process energy requirements. This approach provides a great deal of potential for reducing CO_2. The technology is geared to the large amounts of leftover biomass from agriculture and forestry. The biomass is first converted into an energy-rich intermediate product, bioliqSynCrude, using flash pyrolysis, and then into synthesis gas, from which the required end products are generated by means of chemical synthesis. A pilot plant covering the entire process chain from bales of straw to the fuel pump is being set up and operated at the Karlsruhe Institute of Technology (KIT).

Dr. habil. Nicolaus Dahmen
Karlsruhe Institute of Technology (KIT) in the Helmholtz Association
www.kit.edu
nicolaus.dahmen@kit.edu

Man has been using hydropower to generate energy for centuries.

Hydropower

Hydropower accounts for around 15 percent of global power generation. As such, it is by far the most significant renewable energy source for power generation. Hydropower stations exist in a variety of sizes, from the decentralized small power station with an output of a few dozen kilowatts, to large-scale power stations that can produce several thousand megawatts of power. Equally important is the role of hydropower as an energy storage device in the form of pump storage stations, which help cover peak power demands. The potential of hydropower in Europe has been largely exploited, but yields can be increased by modernizing the technology, some of which is very old. Additional opportunities emerge by tapping into options that have been underexploited to date, such as ocean currents, tides or waves. Hydropower will also benefit in future from further optimized turbines, generators and transformers.

Sustainable development in the energy sector
Investment in the future

In the "Financing Solutions for Innovation and Sustainable Development in the Energy Sector" project, scientists are analyzing the role of the financial sector within the socio-technical system, the relationship between private- and public-sector players, and innovative financing solutions on the basis of the energy sector at a German and European level, as well as in an extra-European context. As part of these case studies, solar energy is used by way of example to examine the negative repercussions and the challenges posed by the financial and economic crisis, as well as the reactions of private- and public-sector players. Regions with financial and energy markets at different stages of development are compared; the transferability is verified by taking biomass usage as an example.

Prof. Dr. Robert Kappel
GIGA German Institute of Global and Area Studies
www.giga-hamburg.de
kappel@giga-hamburg.de

Hydropower
Technology for new energy sources

Hydropower is among the oldest energy sources known to man. The technology is relatively mature, particularly for large conventional hydropower stations; compelling research options emerge in relation to the optimum management of pump storage stations, the networking of numerous small power stations and the exploitation of new energy sources such as ocean currents, tides or waves. The Kassel branch of the Fraunhofer Institute for Wind Energy and Energy System Technology IWES is conducting research, among other things, into small hydropower stations and ocean energy systems. Work on control technology, modeling and simulation lies at the heart of this research, as does involvement in corresponding development and pilot projects.

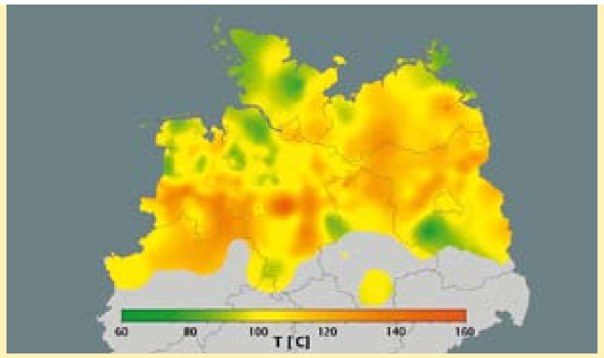
Dipl.-Phys. Jochen Bard
Fraunhofer Institute for Wind Energy and Energy System Technology IWES
www.iwes.fraunhofer.de
jochen.bard@iwes.fraunhofer.de

Geothermal energy could be used much more as an energy source than in the past.

Geothermal energy

Geothermal energy from a depth of several thousand meters offers a constant, predictable energy supply. The hot water can be used for heating, as process heat or to generate electricity. Since the temperatures are often not sufficient for a normal steam turbine process, organic Rankine cycle (ORC) or Kalina processes are used. These technologies are now available commercially, but further development is still required to increase efficiency.

Since natural thermal water deposits are limited, water often needs to be pumped from the surface into the ground through a borehole and the hot water routed back to the surface by means of a second borehole. The required crevices and gaps inside the Earth frequently have to be produced artificially by injecting water at very high pressure. Drilled holes are very expensive; reliable forecasts of heat distribution underground, the stress regime and a structural analysis of the subsurface are therefore key elements of exploration technology, which still needs to be developed in certain areas.



Data for planning
Heat from the depths

Sound knowledge of the subsurface is a critical success factor in the planning and design of large geothermal plants. Primary data on temperatures, permeability and many other rock properties need to be collated and evaluated. Database projects such as the Geothermal Information System GeotIS provide the basic knowledge needed to utilize research specifically, and to reliably deploy and plan geothermal plant technically and financially. Computer modeling, academic involvement in large-scale experiments along with specific measurement and interpretation of the resulting data are helping research institutions promote the usage of deep geothermal energy, thereby laying the foundations for environmentally friendly future energy.

Dr. Rüdiger Schulz
Leibniz Institute for Applied Geophysics
www.liag-hannover.de
ruediger.schulz@liag-hannover.de

Geothermal energy research
Research laboratory for geothermal energy

Geothermal energy is available anytime, anywhere, regardless of the season or climate, and is practically inexhaustible. In addition to supplying heat, it is therefore also becoming an increasingly interesting proposition in Germany for meeting base-load electricity needs. The GFZ German Research Centre for Geosciences is looking at new processes that will make heat and electricity from geothermal energy commercially viable, even at our latitudes. The on-site research lab at the GFZ is the world's only facility to investigate sedimentary geothermal deposits under natural conditions. Scientific experiments are being conducted in the facility, new borehole measurement processes utilized and technical system components tested and honed in operation.

Dr. Ernst Huenges
Helmholtz Centre Potsdam –
GFZ German Research Centre for Geosciences
www.gfz-potsdam.de
huenges@gfz-potsdam.de

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Fax +49 228 833-199
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53175 Bonn
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80686 München
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53175 Bonn
Phone +49 228 30818-0
Fax +49 228 30818-30
org@helmholtz.de
www.helmholtz.de
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Fax +49 228 887-110
post@hrk.de
www.hrk.de
President:
Prof. Dr. Margret Wintermantel

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Eduard-Pflüger-Strasse 55
53113 Bonn
Phone +49 228 30815-0
Fax +49 228 30815-255
info@leibniz-gemeinschaft.de
www.wgl.de
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80539 München
Phone +49 89 2108-0
presse@gv.mpg.de
www.mpg.de
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Emil-Abderhalden-Strasse 37
06108 Halle (Saale)
Phone +49 345 47239-0
Fax +49 345 47239-19
leopoldina@leopoldina.org
www.leopoldina-halle.de
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Wissenschaftsrat
Brohler Strasse 11
50968 Köln
Phone +49 221 3776–0
Fax +49 221 388440
post@wissenschaftsrat.de
www.wissenschaftsrat.de
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Dr. Martin Thum
Christa Schraivogel (picture)

Fraunhofer-Gesellschaft
Press and Public Relations
Hansastrasse 27c
80686 München, Germany
martin.thum@zv.fraunhofer.de

Brochure authors
"Researching: Energy"
- Dr. Harald Bradke, Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe
- Dr.-Ing. Christian Doetsch, Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, Oberhausen
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