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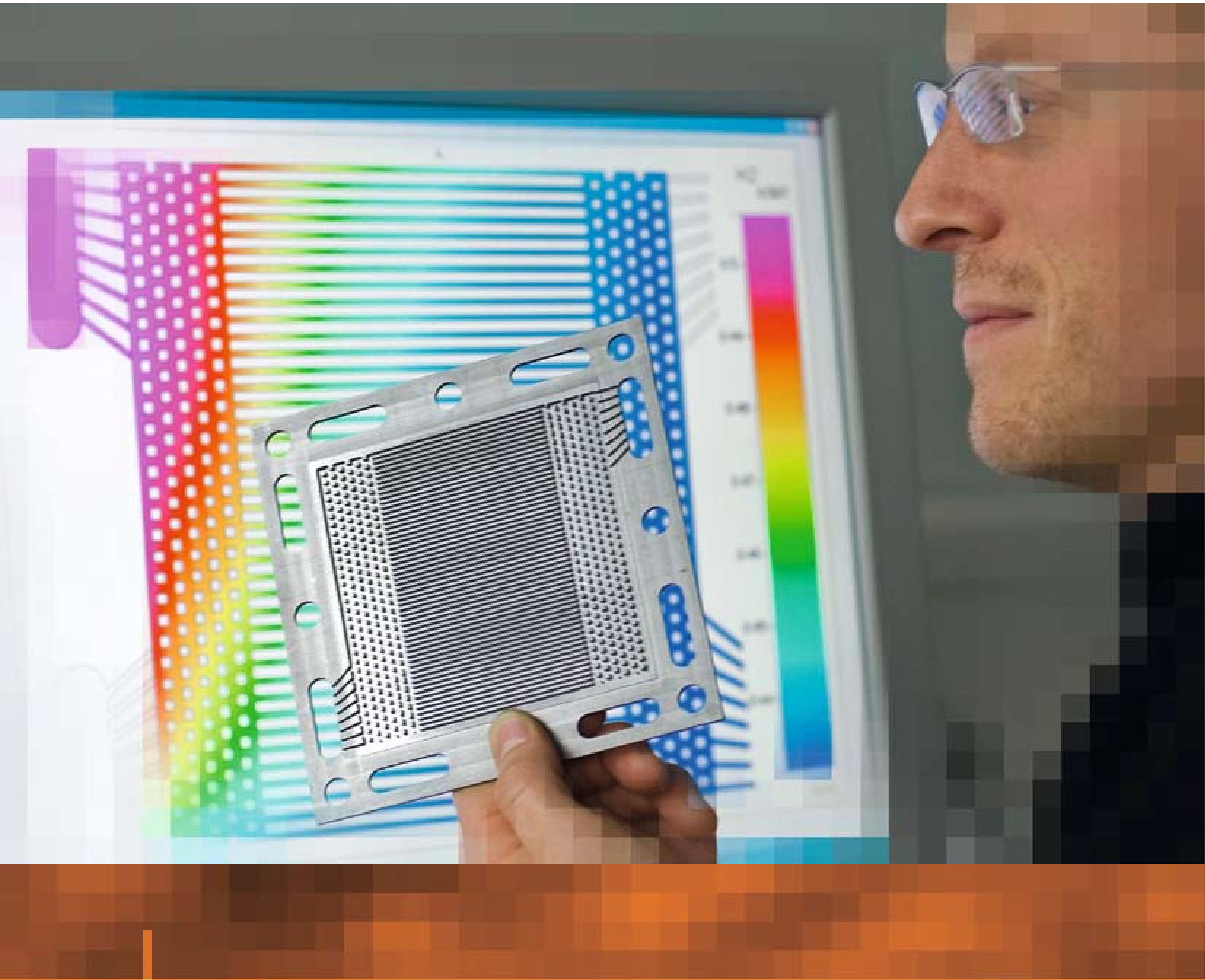

Climate Protection and Energy Efficiency

Research, Development and Demonstration of Modern Energy Technologies

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At the Centre for Solar Energy and Hydrogen Research (ZSW) in Ulm, the gas distributor structures of a fuel cell component are modelled on a computer.

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and Technology

Energy

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Contents

Preface

At the beginning of the 21st century, the challenges for long-term energy supply have become even clearer: economic growth in many countries worldwide, particularly in the threshold countries such as China or India, has led to an enormous additional demand for energy, which obviously cannot be satisfied simply by rapidly expanding the energy available. In the long run, this leads to high oil and gas prices, which pose an extra burden for industry and consumers and could become a risk factor for growth and employment in Germany. After all, emissions of greenhouse gases are increasing with the growing combustion of coal, oil and gas, making it all the more urgent to implement measures to protect the Earth's atmosphere.

These facts make it clear that we must now modify our energy supply system faster than ever before. In the process, the issue of handling energy efficiently has become the focus of attention in politics. We know that increasing energy efficiency is the most effective and economic way of creating a reliable and climate-friendly energy supply system. It is also the best measure for counteracting high energy prices.

Improvements in energy efficiency depend on a number of factors – in the long term particularly on technological progress and the use of modern technology. The development of innovative technologies aiming to increase energy efficiency is therefore a strategic element in every good energy policy. However, new technologies do not fall from the sky. They are the result of many years of research. Only the fruits borne by research and development over the course of the years will find their way onto the market. This makes targeted research and development activities all the more urgent, particularly in those areas that appear to have the greatest potential for saving energy and where modern technology can help to limit excessive burdens on industry and consumers.

According to these criteria, the Federal Ministry of Economics and Technology (BMWi) has increased its funding of programmes in the field of non-nuclear energy research and refocused its efforts in the "Technology Programme for Climate Protection and Energy Efficiency". The programme centres on traditional areas such as "modern power plant technologies", "fuel cells, hydrogen" and "energy-optimised buildings". New research priorities have also been added on topics such as "energy-efficient communities", "efficient electricity use and storage" as well as "high-temperature superconductors".

All of these support measures are part of an overall strategy for improving energy efficiency and they are supplemented and reinforced by other BMWi programmes. These include the transport research programme, measures within the national energy efficiency action plan as well as individual initiatives such as the "E-Energy" programme, which aims to support the efficient generation, distribution and use of electricity through innovative information and communications technologies.

The funding of innovation and modern energy technologies is one of the policy fields that must be further strengthened to allow Germany to rise to the challenges in the energy sector. The selection of research and demonstration projects described in this brochure show that we are on the right track.

Federal Ministry of Economics and Technology

Challenges for energy research

A reliable, economic and environmentally friendly energy supply is the backbone of every modern economy ensuring growth, employment and prosperity. Without energy, there can be no development. And as we know – if the energy supply sector is not restructured, no progress will be made in climate protection.

The German Federal Government set the course for energy policy over the next few years when it officially adopted the Integrated Energy and Climate Programme on 5 December 2007. The strategic features of this programme are determined by three main aims to be achieved by 2020:

- an increase in macroeconomic energy efficiency,
- an increased proportion of renewable energies in satisfying primary energy needs, and
- a decrease in emissions of greenhouse-relevant trace gases.

Targets for increasing the macroeconomic energy efficiency form the heart of the Federal Government's policy. If energy efficiency and the associated decrease in primary energy consumption in Germany are not improved, it will prove impossible to achieve the planned increase in the proportion of renewable energies used in supplying energy: by 2020, this should be 25 – 30 % in the area of electricity and 14 % in the area of heat. If primary energy consumption is not cut, the aim of reducing greenhouse gas emissions by up to 40 % by 2020 will also be difficult to achieve.

In improving energy efficiency, the German Federal Government aims to halve the specific primary energy consumption, which is the primary energy consumption required to generate a unit of gross domestic product, by 2020 in comparison to the level of 1990. If we take a look at the progress made between 1990 and 2007, it becomes clear that the specific primary energy consumption must be reduced by at least 2.7% per annum between today and 2020. Otherwise, the Federal Government's energy saving target will not be met. This in turn would lead to a situation where other energy and environmental policy targets set by the Federal Government would be in danger of becoming difficult if not impossible to reach.

Reducing the specific primary energy consumption by 2.7% per annum is without doubt an ambitious goal. It goes well beyond anything achieved in the past. There has been no comparable period in Germany since 1980 when an attempt to sink the specific primary energy consumption by more than the average value of 1.8 % per annum would have been successful. The 1.8 % mark therefore represents a benchmark according to which we can measure the current policy target. In terms of the selection and dimensioning of measures for implementing the 2.7% improvement in efficiency, it should also be noted that the process of reducing the specific primary energy consumption is tending to slow down. This corresponds to expectations considering the very high efficiency standard that already exists in Germany. The challenge lies in breaking this trend and speeding up the conservation processes.

It is therefore clear that the targets set by the Federal Government with regard to improving energy efficiency necessitate a radical restructuring process.

The Federal Government's Integrated Energy and Climate Programme

The Federal Cabinet adopted the "Integrated Energy and Climate Programme" (IECP) on 5 December 2007. IECP is a comprehensive package comprising 29 measures aiming above all at more energy efficiency and more renewable energies. For example, the percentage of electricity generated in combined heat and power stations is to be increased from the current level of 12 % to 25 % in 2020, the proportion of renewable energies used to generate electricity is to be increased from around 14 % to 25 – 30 % in 2020, and the proportion used to supply heat is to be increased to 14 %. With IECP, the Federal Government has set the course for an extremely modern, secure and climate-friendly energy supply sector in Germany. At the same time, it has established measures for an ambitious, intelligent and efficient climate protection programme. The ultimate aim is an international climate protection agreement after 2012. To this effect, the Federal Government has agreed that Germany will lower emissions by 2020 to 40 % less than the level in 1990. This pledge will only come into effect if the European Union agrees to reduce its emissions by 30 % compared to 1990 during the same period, and if other countries agree on similarly ambitious targets. The key to achieving the targets laid down in IECP consists of innovative energy technologies on both the supply side where energy is generated, and on the consumer side where energy is used. The Federal Government therefore decided to make research and innovation one of the priorities of IECP (measure 25). BMWi's "Technology Programme on Climate Protection and Energy Efficiency" is a key component in this measure.

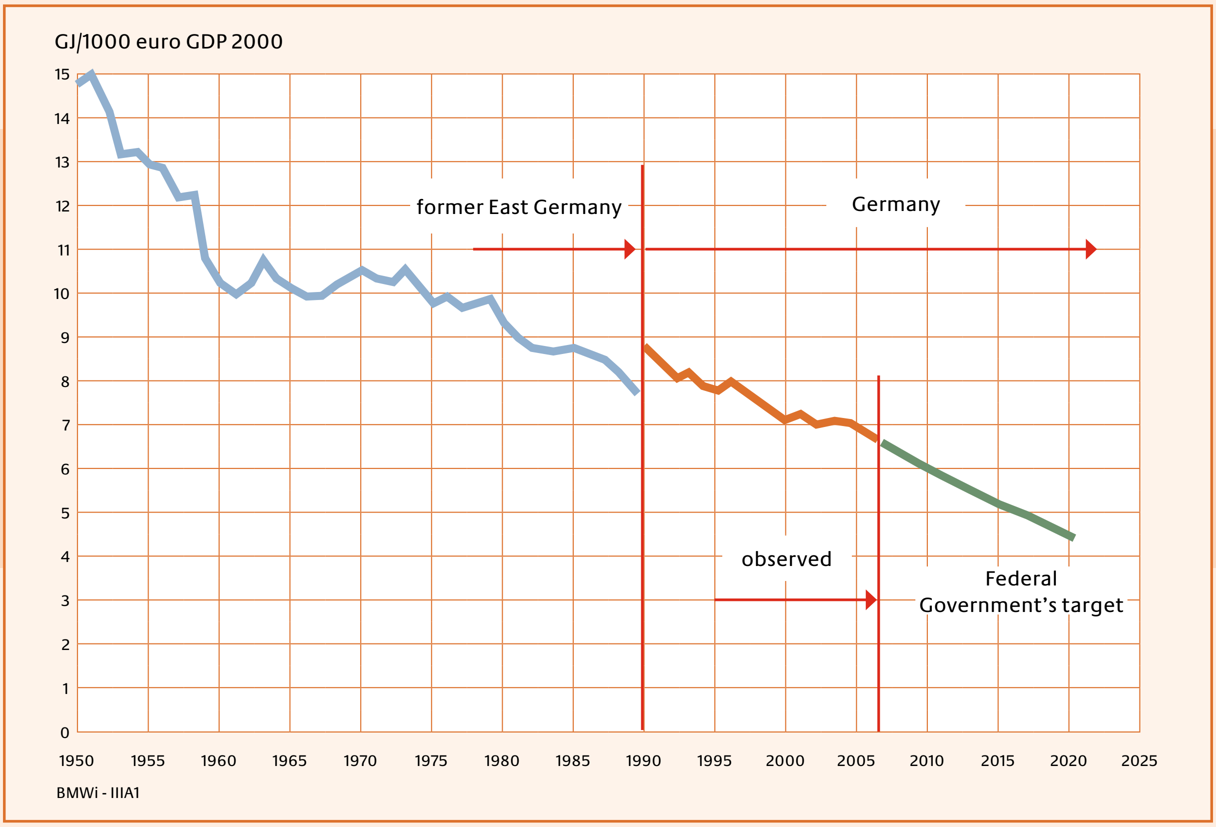


Diagram showing the decrease in specific primary energy consumption in Germany. The economic output increased in 2007 by 2.5% compared to the previous year, while the specific primary energy consumption (unadjusted, in other words without taking temperature influences and the effect of energy reserves into account) decreased by around 7.7%. When the figures are adjusted by the special factors, we are still left with an improvement of around 5%. The absolute figures also reflect the fact that we are on our way towards a modern, efficient and sustainable energy supply. With 13,878 petajoules, the energy consumption in 2007 was at its lowest since the reunification of Germany. Compared to the previous year, the decrease was 4.8%; compared to 1990 it was 6.9%.

Long-term economic growth in parallel with a decrease in energy consumption is possible, but it necessarily implies alterations, structural changes, investments and will initially give rise to costs.

The Federal Government will take precautions to ensure that this restructuring process will not overtax the competitiveness of German industry and that the burden placed on the consumer will be kept to a minimum. A key role is played here by the accelerated application of modern highly efficient and less expensive energy technologies. The Federal Government has taken this into account by placing particular emphasis on "Energy research and innovation" as part of its Integrated Energy and Climate Programme.

The research, development and market launch of new energy technologies is primarily a task for industry. However, the Federal Government supports industry in certain fields, particularly in areas where the development of new energy technologies is considered essential but where companies are not in a position to conduct research and development work or can do so only to a limited degree as a result of particularly high risks or long development times. The challenging political targets for climate protection and energy efficiency and the complex initial situation in the energy sector require a time-differentiated, well-coordinated and comprehensive energy saving and technology policy. The Federal Government is therefore pursuing a broad-based approach, which aims to improve energy efficiency – from energy generation and energy conversion to energy transport and the use of energy by the consumer. This approach is based on the pursuit of two complementary lines of action:

- In order to sustain and speed up the dynamics of the energy conservation process, the Integrated Energy and Climate Programme also contains a number of measures that can be implemented in the short term. Of particularly importance are targets for the expansion of the combined generation of heat and power, the amendment to the Energy Saving Ordinance, the funding programmes for the energy-efficient modernisation of buildings and the social infrastructure, as well as new guidelines for the procurement of energy-efficient products and services for the Federal bodies.

- In parallel, funding for the research and development of modern energy-efficient technologies will be increased in order to create the prerequisites for an economically safeguarded decrease in specific primary energy consumption in the medium term. This will be primarily ensured by boosting the funding provided by the Federal Ministry of Economics and Technology (BMWi) for market-oriented and application-oriented projects.

After the decision was made by the Federal Government to adopt the Integrated Energy and Climate Programme, BMWi reorganised its funding activities within the framework of the 5th Energy Research Programme in the field of modern energy technologies under the name of the “Technology Programme on Climate Protection and Energy Efficiency”. A total of approx. € 446 million will be made available for this area over the next four years (2008 – 2011).

BMWi’s funding programme “Technology Programme on Climate Protection and Energy Efficiency” focuses on the following fields:

- modern power plant technologies (inc. CO_2 separation and storage – COORETEC)
- combined heat and power generation, district heating
- fuel cells, hydrogen
- efficient use of electricity, storage facilities (inc. the new initiative on high-temperature superconductors)
- energy-optimised buildings (inc. the new initiatives “energy-efficient communities” and “energy efficient schools”)
- energy efficiency in industry, commerce, trade and services

Activities on these priority areas are flanked by energy-related funding measures in multimedia research (“E-Energy: ICT-based energy systems of the future”), transport technologies (such as alternative drives and fuels), and research work at the German Aerospace Centre (power plant technology, fuel cells).

The political challenges at the beginning of the 21st century are determined by climate protection and energy efficiency. The response to these challenges lies in more research and development, as well as a quicker application of modern energy technologies.

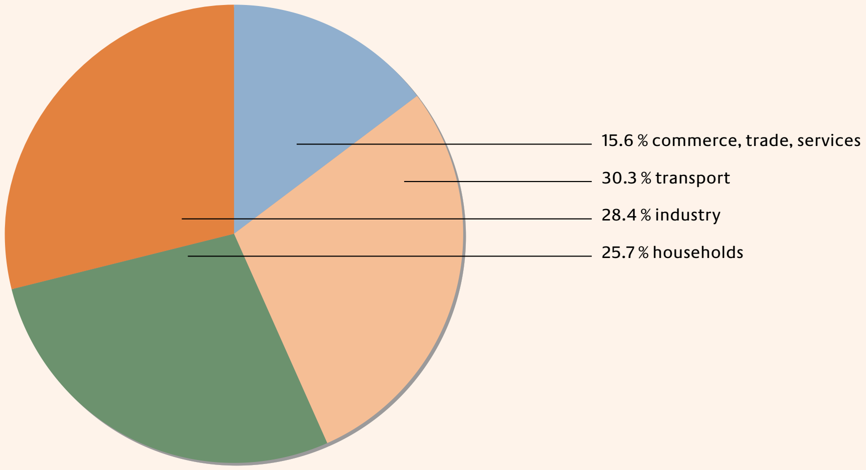
The Federal Government’s 5th Energy Research Programme

The Federal Government has defined the targets and priorities of its energy research policy together with the corresponding support mechanisms in an energy research programme covering several years. On 1 January 2006, the 5th Energy Research Programme on “Innovation and New Energy Technologies” was launched. The programme, which was decided upon under the chairmanship of BMWi (responsible for the Federal Government’s energy research policy) in cooperation with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the Federal Ministry of Food, Agriculture, and Consumer Protection (BMELV) and the Federal Ministry of Education and Research (BMBF), will provide the basis for the Federal Government’s funding policy over the next few years. The aim is to foster the transition to a sustainable energy supply through innovation and technological progress. In the short and medium term, the programme will make a concrete contribution to achieving current political targets, most importantly ensuring a balanced energy mix, an increase in energy productivity, an increase in the contribution of renewable energy carriers to the primary energy consumption, as well as the reduction of greenhouse gas emissions. In the long term, it will help to improve the responsiveness and flexibility of energy supply systems by safeguarding and expanding the technological options. Having adopted IECP, the Federal Government reaccentuated and intensified its funding activities within the framework of the 5th Energy Research Programme. This saw BMWi reorganising its funding activities in the field of non-nuclear energy technologies under the name of the “Technology Programme on Climate Protection and Energy Efficiency”. Within the framework of energy research, the Federal Government will provide a total of around € 2.1 billion in the form of funding between 2008 and 2011 for the research and development of modern energy technologies. In this way, the Energy Research Programme will make an important contribution to the necessary adaptation and modernisation of the German energy supply system. The programme will also boost growth and employment in Germany, and through the export of highly efficient energy technologies, it will make an effective and essential contribution to protecting the Earth’s atmosphere throughout the world.

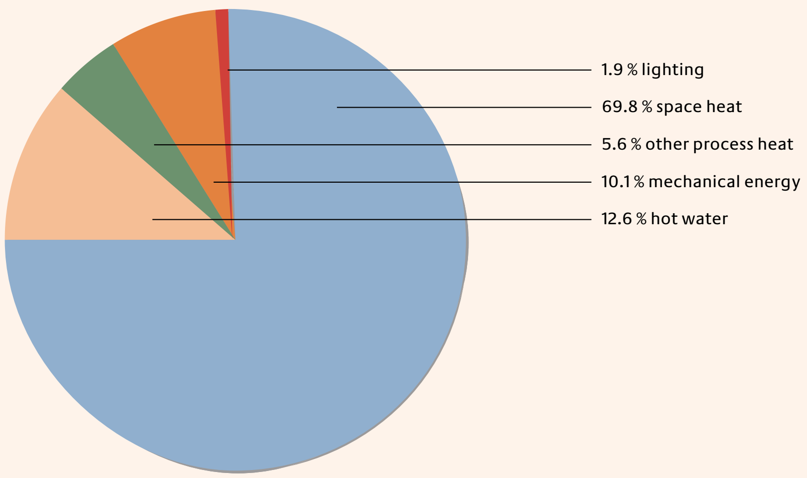
Efficient energy use

Apart from changes in consumer behaviour and an enhanced use of renewable energies, it is above all by increasing the efficiency of energy conversion and energy utilisation that we will facilitate the transition to a sustainable energy future. Energy research has the task of developing innovative technologies, products and concepts for this purpose. An important part is played by energy-optimised construction for residential and commercial premises and a more efficient use of energy in existing buildings since increasing the energy efficiency in the building sector is one of the keys to solving our energy problems. Another important task is increasing energy efficiency in industry and in the sector of commerce, trade and services since together the two sectors account for the greatest energy consumption. Furthermore, the electricity sector – including more efficient electricity storage – is of great significance for the further development of the energy supply.

Distribution of final energy consumption in Germany in 2007 between various consumption sectors



Distribution of final energy consumption in private households according to application



Arbeitsgemeinschaft Energiebilanzen, as of 26.09.2008

The two diagrams show that private households have particularly great potential for an increase in energy efficiency. Households account for almost 26 % of final energy consumption in Germany, of which almost 70 % is used for space heating.

In addition to issues of structural engineering, architects and construction managers are giving increasing consideration to interactions between systems and facilities in a building with respect to their energy-optimisation strategies in order to achieve an overall improved energy balance. An interview with Dipl.-Ing. Hans Erhorn, head of the Heat Technology Department of the Fraunhofer Institute for Building Physics in Stuttgart, Holzkirchen and Kassel, and lecturer at the University of Stuttgart.

"Energy balances are becoming more and more complex"

? Energy optimisation in buildings, energy-efficient communities – where do we stand in Germany?

! As far as efficient energy utilisation in buildings is concerned, until a few years ago we focused almost exclusively on optimising heating systems. For smaller residential buildings this type of consideration may still be appropriate, but for larger buildings such as schools or office buildings, the effects of other building service systems, such as ventilation, air conditioning or lighting, must be integrated into the energy balance. In order to provide reliable parameters for manufacturers, planners and users, we have, for example, erected a multi-storey modular test building for energy and indoor climate studies at our institute site in Holzkirchen. Here we can study in detail the energy input through the façade, the energy consumption, the lighting and the comfort of the indoor climate in interaction with the technical systems. It is no exaggeration to say that in an international comparison we in Germany are in a leading position with respect to evaluating the efficiency of energy utilisation.

? Does the integration of plant engineering in the energy balance of buildings have an effect on technological developments?

! Ever since we have been in a position to make a holistic assessment of buildings with respect to energy, that is to say, in their interaction with the installed facilities such as heating, ventilation or shading systems, we have experienced a downright technological explosion in façade and plant engineering. Thus, for example, protection against the sun in a building no longer simply has the function of providing shade. Nowadays, systems of blinds are designed in such a way that, on the one hand, they provide the building with an optimum supply of daylight during the day without, for instance, dazzle from the winter sun making computer screens difficult to read in offices, whereas, on the other hand, depending on the season, the incoming solar radiation can be optimally used for air conditioning. Plant engineering can only fulfil such multidimensional demands on the basis of an overall energy balance since, in this way, the extent to which these demands promote or impair efficient energy utilisation become visible and verifiable.

? A new market for German industry?

! We have observed that manufacturers of building services now keep a very close eye on synergetic effects between the different systems. An important link in the chain is, of course, the automation technology by means of which this as yet untapped energy potential can be exploited. It is, for example, becoming easier to couple classic heating systems based on fossil energy carriers in an energy-efficient manner to systems that make use of renewable energies such as solar radiation.

? What difference does such synergetic energy optimisation make?

! In the field of the energy-efficient modernisation of schools, we have been able to gather a great deal of very positive pioneering experience over the past few years. It became apparent that with the technologies currently available the energy demand of such buildings can be easily reduced by 50 to 70 % – and moreover in an economic manner. If you consider that the majority of the 40,000 school buildings in Germany will have to be modernised in the next few years, then you can see what an enormous potential for energy savings is lying dormant. We estimate this potential to be in the order of 7 million megawatt hours per year.

? What is the trend in energy balances?

! The areas covered by energy balances are getting bigger and bigger. About four years ago, a reorientation began in the planning sector. The focus was shifted from concentrating on optimising the heating engineering, which had been usual up to then, to minimising the overall energy consumption of a building. On this basis, we are now taking another step by including the energy supply in our considerations. And the next step is already in sight. This will involve the energy-optimised town. On a very much more complex level, this also involves achieving an optimum between energy demand, on the one hand, and energy supply, on the other.

Energy-optimised buildings

The largest office building in the world constructed according to passive house standards was erected in Ulm. In spite of its low energy consumption, the "Energon" is comfortable in both summer and winter. On the left, a view into the atrium of the Energon.

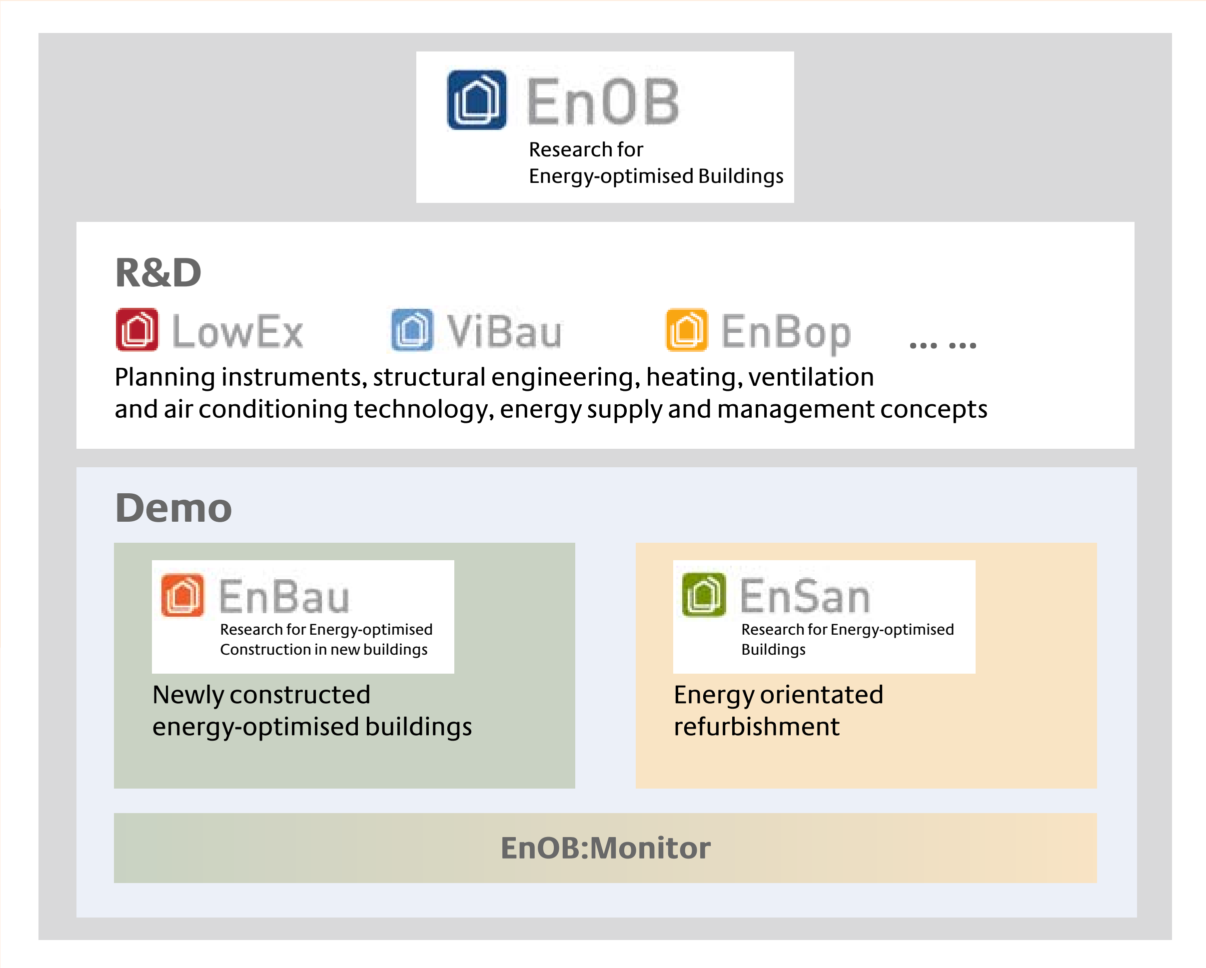
The best energy is that which isn't needed. Or to put it another way: increasing the energy efficiency is one of the most effective and economical ways of ensuring security of supply and protecting the climate.

This is particularly true of buildings. More than 80 % of all buildings in Germany are old housing stock and were erected at times when there were neither legally binding regulations for energy consumption nor any awareness of energy-optimised construction. It is therefore no wonder that in residential buildings today more than one third of the entire final energy is devoured by heating and hot water. According to an estimate by the Fraunhofer Institute for Building Physics (IBP), if the residential building stock alone were modernised so that consumption dropped to 35 % – which would be easy to achieve technologically – then this would result in potential annual savings of 640 terawatt hours. "Measures for increasing efficiency thus have a potential which is greater by a factor of ten than what renewable energies could contribute to energy generation," the head of IBP, Professor Gerd Hauser pointed out. About 600,000 residential units are modernised each year in Germany, but experts estimate that this only specifically concerns a reduction in energy consumption in every third case.

In its new Energy Efficiency Action Plan (EEAP), the Federal Government is therefore focusing on the building sector. EEAP represents the incorporation of the EU directive on energy end-use efficiency and energy services into German legislation and identifies the measures to be taken to achieve the aims of the directive. It is planned to cut national final energy consumption by 9 % by 2017. Several of the measures mentioned in the plan target the building sector, including:

- A significant tightening-up of the energy requirements for buildings
- A continuation of the CO_2 building modernisation programme
- Increased investment in the energy efficiency of public buildings
- Promotion of energy-saving contracting for residential buildings

Energy-optimised buildings are not a vision. Even today it is possible to construct buildings cost-effectively with drastically reduced heating and cooling requirements; these buildings are comfortable to live in without sophisticated technology. This can be achieved by combining four instruments: very good protection against heat and sun, sufficient thermal storage capacity, an envelope that is air-tight with no heat bridges, and comprehensive heat recovery. This is the starting point for the research initiative "Energy-optimised Buildings" (EnOB) of the Federal Ministry of Economics and Technology (BMWi). This initia-



Structure of the research initiative “Energy-optimised Buildings” of BMWi (www.enob.info).

tive aims to promote the development of innovative components and to implement pilot projects that significantly reduce the primary energy requirements of buildings in comparison to the present state of the art. For modernisation work in the non-residential sector, EnOB demonstration projects must achieve energy savings at least 30 % greater than the figure laid down in the regulations for new buildings and for the modernisation of residential buildings at least 50 % more. Furthermore, new efficient materials and systems for structural engineering and technical facilities for buildings developed as part of EnOB must also be employed.

The funding concept for “Energy-optimised Buildings” is broken down into the two areas of “EnOB-R&D” and “EnOB-Demo”, with the demonstration and evaluation of innovative concepts being further subdivided into new (EnBau) and existing (EnSan) buildings. The area of EnOB R&D is divided into modules according to topic (low-exergy technologies (LowEx) and vacuum insulation in the building sector (ViBau)), and will be gradually extended to include other modules, for example in the field of optimising the operation of buildings (EnBop). In “EnOB: MONITOR”, extensive accompanying research work is being funded. Past projects funded by BMWi in EnOB were very successful. Many of the technologies, materials and systems developed and demonstrated in the projects are now available commercially.

Decentralised heating pump: mighty midget!

Central heating systems have one big disadvantage: about half of the pumping power is lost due to hydraulic losses. Extremely small pumps that require on average just one watt of power and which supply each radiator separately are much more efficient. This is shown by the results of a research project funded by BMWi. The pumps are no bigger than a thermostat, operate almost silently and only spring into action if heat is actually required. Experiments in an existing detached house showed that the fuel consumption is reduced by 20 % and the electricity requirements for the pumping power by up to 90 %. Moreover, decentralised heating pumps are even more convenient. Rooms can be brought to the required temperature quickly and the heat supply is more precise. Wilo, a manufacturer from Dortmund, expects to launch these pumps onto the market in early 2009.

The Darmstadt solar house – winner of the US Department of Energy's 2007 Solar Decathlon – designed and constructed by students at Darmstadt University of Technology is a project funded by BMWi as part of EnOB.

The necessary conditions have thus been created for tightening up the regulative standards. Up-to-date information on the large number of completed and ongoing projects in EnOB can be obtained from the website **www.enob.info**. Some examples will be presented in the following.

A house with no heating

Buildings constructed or modernised today will have a lifespan of many decades. "It is therefore necessary for economic considerations to focus on the cost over the entire life cycle of buildings," said Professor Karsten Voss from the University of Wuppertal. This is all the more important since as experience has shown the operating cost of large buildings exceeds the construction cost after just seven or eight years.

Some old uninsulated buildings consume more than 200 kilowatt-hours of heat and electricity per square metre and year (kWh/m^{2}a). Numerous pilot projects funded by BMWi in past years have demonstrated that modernisation cuts this consumption by half and can already be achieved in a cost-effective manner. In fact, a lot more is possible. So-called three-litre houses are already state of the art. Such three-litre houses only consume about 30 kWh/m^2 of heating energy per year – in terms of heating oil this corresponds to roughly three litres – and thus about 80 % less than old buildings. This standard of modernisation is still relatively expensive. However, experts assume that it will become established in the long run. The days are long gone when the heating and operating costs of a building could be regarded as "incidentals". Rising prices for oil and gas mean that incidental expenses will also increase. Low energy costs will therefore enhance the value of a property in future.

However, the three-litre house does not exhaust the technical possibilities. Passive houses reduce the consumption of heating energy even further and if they have an efficient ventilation system they can largely be operated without separate heating or air-conditioning systems. In passive houses, the necessary heat is obtained by other methods. Optimal insulation, for example, conserves the heat from solar radiation, heat emitted by electric appliances or heat recycled from the exhaust air so effectively that it is possible to live comfortably in a house even without additional heating. According to information from the Darmstadt Passive House Institute, in 2006 there were more than 900 buildings in Germany constructed according to passive house standards – almost 60 % of them detached homes. The evaluation of individual houses and also whole housing estates has shown that it is possible to live comfortably throughout the year

Darmstadt solar house wins US competition

Students at Darmstadt University of Technology proved that the sun can provide all the energy necessary for a building's daily requirements. They designed and constructed a house with a floor area of 74 m^2 supplied solely by solar and environmental energy. This was the winning entry in the US Department of Energy's Solar Decathlon at the end of October 2007 – an international competition to find demonstration models for energy-efficient homes and to introduce the topic to the general public. The winning German design is composed of three envelopes. The outer layer consists of flexible oak slats equipped with solar cells. The modules generate electricity and protect against overheating, burglars and inquisitive people looking into the house. The second layer consists of sun protection glass and vacuum insulation panels. The walls store heat by means of microencapsulated paraffin, while the ceiling is designed with a cooling function and also has an integrated lighting system. The third layer comprises the core of the house with bathroom, kitchen and technical systems. The simulation required for such an ambitious project was performed as part of a research project, so that the concept is now being put through its paces at the Darmstadt site.

Construction work began in 2008 on the Science College at Haus Overbach, a school near Jülich. It is being funded within the framework of EnOB as an "EnEff:School". The school is aiming to become a "two-litre school" by means of various energy measures including skilful load management, after all: "The students bring their heat with them."

with a total energy consumption of less than 120 kWh/m^2a (i.e. total primary energy including electricity for household appliances and lighting). This value is one of the three criteria for a passive house.

Even zero-energy or plus-energy houses are no longer just a vision. Such buildings do not need any external energy in the annual budget because they can generate all the electricity and heat they require themselves, usually by means of solar facilities and combined heat and power generation. As part of EnOB, work is currently being carried out on a technical definition of a zero-energy house, and construction concepts are also being devised and evaluated.

Building with the sun

Energy-optimised buildings can already be achieved with the technologies available today. In Germany, this is due in large part to the continuity of the funding policy for efficient energy utilisation since many of these innovative energy technologies only managed to make the decisive breakthrough with the aid of R&D projects funded through EnOB. This is, for example, true of thermal solar installations, which, particularly in the case of large buildings with high and, as far as possible, uniform hot water requirements, provide a reliable supply of environmentally friendly heat. The technical possibilities have reached such a level of maturity today that, at least for the preheating of service water by solar energy, they are now an intrinsic component of building modernisation.

The use of solar thermal power should always be taken into consideration as part of a comprehensive modernisation concept in which the energy requirements of the building should first be minimised as far as possible and the conventional heating system replaced. Under these conditions, solar thermal power can passively and actively reduce heating energy consumption by up to 50 %. The specific capital costs of the facilities diminish with system size. Collector surface areas of more than 100 m^2 can supply housing estates, hotels, retirement homes and hospitals with heat at a cost of 10 to 13 cents per kilowatt-hour – provided that the facilities have the proper dimensions, are operated to capacity and are of a simple design. Furthermore, coupling conventional heating energy and solar energy is particularly effective outside the heating season when there is a low demand for heat. In summer, solar thermal power provides enough energy for all hot water requirements.

Using conventional collectors, the sun generates heat at a low temperature level. This level is, however, sufficient to provide centralised cooling and dehumidification for buildings – especially if they need air conditioning throughout the year such as laboratories and buildings with a high thermal load. As part of pilot and demonstration projects, both closed cooling systems such as adsorption and

Due to the extremely low thermal conductivity, highly effective vacuum insulation panels (VIPs) are only a few centimetres thick. The interior of the VIP is shown here with a white polyurethane edge strip; the finished surface can be a covering of high-grade wood veneer, oriented strand board (OSB), glass, aluminium or stainless steel.

absorption cooling machines as well as open cooling and dehumidification processes were tested. For example, the German Press and Information Ministry in Berlin has a solar-assisted absorption chiller configuration. In the summer, the plant is powered exclusively by heating energy from a solar collector area. Excess cooling power is used by the computer rooms of the Information Ministry which have to be cooled throughout the year.

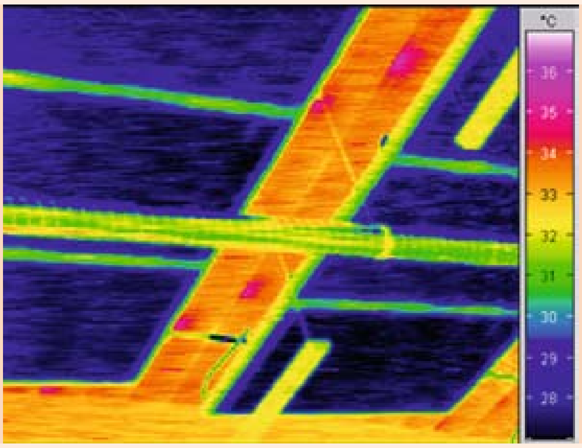
VIP insulation

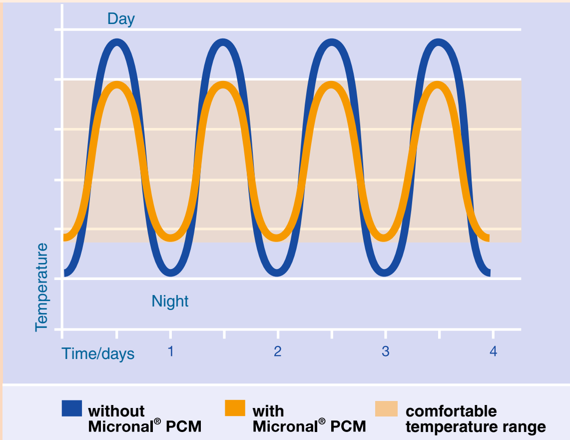
Energy-efficient buildings need optimum insulation. In the case of passive houses, 30-centimetre-thick insulating layers and thus wall thicknesses of up to 60 centimetres are by no means seldom. However, in the case of modernisation, the external dimensions are often restricted by neighbouring houses or building lines. Even in the case of new buildings, thick insulation can only be provided at the expense of useful interior area. An alternative is so-called vacuum insulation panels (VIPs), which have a thermal conductivity five to ten times lower than conventional foam or fibre insulating material. VIPs consist of a porous core which is sealed in diffusion-resistant plastic sheeting in a vacuum chamber. Not least due to the many years of funding provided by BMWi for research and development concerning VIP technology, this process is already technically mature and available on the market.

By means of new buildings completely insulated with VIPs, BMWi has shown that vacuum insulation significantly increases the energy efficiency of residential buildings. Demonstration buildings have been erected in both Neumarkt in the Upper Palatinate and in Ravensburg entirely prefabricated of wood and concrete with integrated VIPs just a few centimetres in thickness. The measurements show that although the walls are only 27 to 32 centimetres thick, instead of 60, the consumption of heating energy is similar to that of passive houses. A quality association – independent of the manufacturers – plans to define and verify quality criteria, processing guidelines and testing regulations for VIPs in cooperation with authorised test institutes. This represents the transition from the R&D stage to a market launch.

Heat and cold from the ceiling

Even today, the heating and cooling of buildings accounts for about 40 % of total energy consumption in Germany. In future, it will be even more. Since hotter summers are to be expected in Central Europe and the internal heat loads of buildings are increasing (computers and domestic appliances), more and more buildings have to be cooled in order to satisfy users' requirements for thermal comfort. Today, there are environmentally friendly alternatives to conventional air conditioning: so-called thermo-active building systems (TABS). The basic idea is quite simple. Build-





PCMs (phase change materials) can be used to store cold and heat. The picture on the left demonstrates the cooling effect of PCM ceiling elements (blue zones). On the right, a comparison of the temperature curve in a residential or office area with (orange curve) and without (blue curve) PCM components.

ings can be heated and cooled if the ceilings, walls and floors are turned into large-area radiators or cooling surfaces. To this end, banks of tubes or thin plastic piping are usually set into the concrete components. Water flows through these pipes and – depending on room temperature – they are used for heating or cooling. Experts estimate that even today every third new office building in Germany is equipped with these systems.

TABS are energy-efficient. The large heat exchange area for heat transfer means that even small differences in temperature of a few °C are sufficient to heat or cool rooms. The components use natural heat sinks such as the soil, groundwater or night air to equalise the temperature. An evaluation of three newly constructed buildings from the EnOB programme in which TABS were tested shows that the primary energy consumption was lower than that of new standard office buildings by a factor of two to three. However, TABS are sluggish so that heat transfer via radiation and convection takes time. Peak loads must therefore be minimised or avoided, for example by optimally insulating the external envelope of the building and all windows must have effective protection against the sun.

This has been successfully implemented in the “Energon” in Ulm, an EnOB demo project (see pictures on p. 12), which is the largest office building in the world constructed as a passive house. The temperature control of the concrete core, together with comprehensive thermal insulation, mechanical ventilation and movable protection against the sun, ensures comfortable working conditions all year round. A total of 40 geothermal probes extract cool groundwater from a depth of 100 metres, which then flows through pipes in the concrete ceilings. The Post Office Tower in Bonn, which is also cooled and heated using groundwater, is a successful example of how the results of BMWi research funding are now finding commercial applications. Even with an outside temperature of 39 °C temperatures in the south-facing offices do not exceed 26 °C.

Efficient energy use also means efficiently storing heat and cold, which is then made available when required. So-called latent heat storage systems exploit the phase transition of certain materials for this purpose. Phase change materials (PCMs) function according to a simple physical principle. When solid substances – for example paraffin – melt, they take up heat from their surroundings. If the ambient temperature drops, they solidify and emit the heat again. PCMs therefore function like large heat stores which shift cooling loads from the day to the night. In past years, PCM technology has made great progress, not least due to continuous research funding. Ceiling panels, lightweight walls and façade elements incorporating PCMs are now available as are separate cold and heat storage systems suitable for both new buildings and modernisation projects.

The planning and simulation program "PCM express" has been developed for the planning and application of phase change materials. It provides simple support for architects and planners by facilitating a reliable decision-making process for dimensioning PCMs, for example in wall structures or in the case of modifications to the related installations. In particular, the tool supports the low-exergy approach in the form of activated components and energy-saving cooling technology. For the cost-benefit analysis, a cost efficiency calculation was integrated into the program based on the specifications of the VDI 2067 guideline.

TABS and PCMs are so-called low-exergy systems since they are activated even in the case of small temperature differences from the surroundings. Exergy is the term for the fraction of total energy that can perform work. Exergy is therefore the valuable part of energy. BMWi intends to use the EnOB research area LowEX to develop and test new heating and cooling systems which can function with small temperature differences and thus make particularly good use of the energy potential.

Käthe-Kollwitz-Schule in Aachen – an EnSan project – before (top picture) and after modernisation. The building from the fifties, now used as a vocational school, consumes 65 % less energy for heating and hot water as well as 15 % less electricity than before modernisation.

Illumination from the outside

Daylight is important for people's well-being – whether at home or at work. The EU directive on the overall energy efficiency in buildings stipulates that the electricity requirements for lighting non-residential buildings must in future be included in the Energy Performance Certificate for Buildings. This means that for the first time daylight will become a factor for energy efficiency.

The amount of daylight fluctuates depending on time of day, season and weather. Efficient utilisation of natural light must therefore maximise the incidence of light in winter and restrict it in summer. In the past few years, a wide range of technologies have been developed industrially – thanks in part to funding from BMWi: louvred blinds which enable the incident light to be better distributed in a room, optical systems guiding daylight into windowless rooms, self-luminous insulating glass, hollow optical fibres for factories and special glass, namely sun protection glass that darkens automatically in strong sunlight. In the case of switchable glass, the permeability to light and radiation can be adjusted as required. Most of these technologies are still not very common, which is due on the one hand to technical obstacles and on the other hand to the relatively high prices. Furthermore, the systems only function to the users' satisfaction if the light- and energy-related characteristics of the building are recorded beforehand and the lighting then tailored to individual requirements. This is the starting point for ongoing research and development. In the collaborative project funded by BMWi on "Daylight and efficient lighting", coordinated by Berlin University of Technology, amongst other aspects, innovative daylight systems for future buildings are being studied as are the medical effects of efficient lighting on humans.

Energy efficiency in existing buildings

In Germany a great many buildings are owned by local authorities. However, many of these schools, student halls of residence or kindergartens are in need of modernisation; they have no thermal insulation, and the windows and heating systems are outmoded. Model modernisation projects demonstrate that public buildings can cut their energy consumption by

The “Neue Burse” student hall of residence in Wuppertal after modernisation funded through the BMWi EnSan programme.

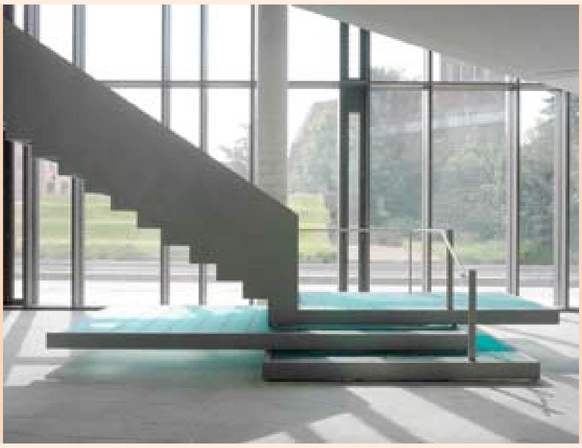
more than 50 % without any particularly sophisticated or expensive technology. Various demonstration projects funded by BMWi have shown that energy-related modernisation is usually a win-win situation. The buildings are renovated, consumption and emissions are cut, and at the same time the users have a more comfortable environment.

Since hardly any new schools are being built, there will be an enormous demand for the modernisation of existing school buildings in the next few years. A good example is a **vocational college in Aachen** (Käthe-Kollwitz-Schule), which was built in the 1950s. Between 2001 and 2003, the outside walls, roof and basement were insulated, heat-absorbing glass was installed, the entire building was connected to a district heat system with combined heat and power generation, and a central ventilation system with heat recovery was installed as well as daylight-controlled lighting. The result was that the energy consumption for heating and hot water was reduced by 65 %, and electricity consumption was cut by about 15 %. Energy-efficient schools will continue to be an important topic in future and in this respect BMWi is making a decisive contribution as part of EnOB with priority being given to “EnEff:School”. Plus-energy schools with be implemented in pilot schemes as lighthouse projects.

Few students are prepared to move into an old hall of residence from the seventies. Not so in Wuppertal – here there are long waiting lists for a place. However, this is only because the “Neue Burse” was extensively modernised in 2003 as part of the EnSan scheme. The original **hall of residence** consisted of two buildings where leaking joints and insufficient insulation had led to whole sections of the building becoming damp. As part of the modernisation work, the large communal groups were replaced by single apartments. The building was completely insulated by prefabricated façade elements, and large triple-glazed passive house windows now flood the rooms with light and warmth from the sun. Heat is supplied by district heat from combined heat and power generation. Measurements show that primary energy consumption has decreased by about 60 % in comparison to the old building. In one of the two houses, it was possible to cut heating energy consumption to 30 kWh/m^{2}a by using passive house components.

The fact that it is possible to achieve an enormous gain in energy efficiency while maintaining high architectural quality was also demonstrated by the modernisation of the **Plappersnut Kindergarten** in Wismar in 2004. Energy consumption has now been reduced by more than two thirds by optimal insulation, solar collectors for the hot water supply, demand-oriented lighting as well as double glazing with two layers of insulated glass. A special feature is the vacuum insulation. Vacuum insulation panels on four outside walls reduce the heat losses of the building by 75 to 90 %. The walls facing inwards to the atrium do not need any insulation. This unheated area between the two wings functions as an intermediate climate zone. The air preheated here enters the buildings and reduces heating requirements. This design has served as a model for more than 300 buildings of the same type in the state of Mecklenburg-Western Pomerania alone. And it also seems to represent a healthy modernisation concept since the kindergarten in Wismar reports that significantly fewer children are off sick.

The modernisation of existing buildings often comes up against technical or economic limits. This is where creativity is called for in order to carry out high-quality modernisation work at low cost. The fact that feasible solutions can be found is demonstrated by the example of the **Thiepval Barracks** in Tübingen – a listed building – which has been converted into an energy-efficient office block. It was only possible to convert the loft by using a lightweight construction method. The ceilings were lined with special plasterboard. The thin boards contain microencapsulated paraffins that store latent heat and provide the same standard of insulation in summer as five centimetres of concrete. This example shows that modernisation to a passive-house standard is economic. The additional expenditure in comparison to modernisation work according to the regulations of the Energy Savings Directive amounts to about € 150 per square metre – an investment that will pay for itself in a few years due to the considerably reduced energy costs. The heating energy requirements of the Thiepval Barracks are now about 23 kWh/m^{2}a while the additional costs for the passive house components were about € 81 per square metre.



Wood and glass characterise the appearance of the new service centre in Eberswalde.

Energy efficiency in new buildings

► Even if the greatest potential for increasing efficiency in the medium term is to be found in the existing building stock the application of innovative technologies is not restricted to older buildings. As a rule, the engine driving new technological developments is actually to be found in the sector of new buildings since here it is possible to work on integrated building designs without making any major compromises. Such integrated concepts are essential for the long-term perspective. Furthermore, the results of the scientific study of the pilot and demonstration projects implemented as part of EnBau are now available and represent a valuable basis for regulatory measures with respect to energy efficiency (Energy Savings Directive – EnEV). Within the framework of EnOB, BMWi's EnBau scheme represents a major focus on efficient energy use in new buildings. Some of the recently funded projects demonstrate the success of this support measure.

► Hard work and ambition are part of every school's curriculum. The building design developed for a new **vocational school** in the Biberach district was also ambitious. Gerhard Müller School – an EnBau project – had to use less than 30 kWh/m^{2}a of energy for heating and hot water to fulfil the three-litre house standard. The building erected in 2004 mainly uses thermoactive ceilings and walls (TABS) for heating and cooling. Staircases, windows and atria are equipped with comprehensive protection against the sun. In 2005, the annual primary energy requirements for heating and cooling the building, ventilation and auxiliary power were already about 70 % lower than for a conventional school building. The engineers weren't the only people who were happy. A survey of the students at the school revealed that they identify themselves with their new school – not least due to the good room temperature and air quality. The new school also has no sign of graffiti or vandalism.

► Eberswalde has also recently established an exemplary model with respect to energy efficiency, comfort and economy. Since July 2007, the district administration has been accommodated in a new **service centre**. The facades of the four compact blocks have vacuum insulation and heat-absorbing triple glazing. The concrete piles under the buildings are equipped with absorber collectors which withdraw heating energy from the soil and in summer release excess heat into the soil again. Funding from the EnOB programme enabled comprehensive specialised planning and the use of modern simulation programs and innovative components. The total energy requirements for heating and hot water for the 15,000 m^2 complex are less than 30 kWh/m^{2}a – at an economic price. The obligation of putting the building work out to public tender and the division of the work into small packages made it possible to allocate the work to well-qualified and cost-efficient building contractors. As a consequence, the construction costs were less than € 1300 per m^2 of floor space.

Well insulated facades and triple-glazing for thermal heat protection ensure low energy consumption in the new service centre in Eberswalde. A sophisticated design involving daylight and artificial light facilitates energy-efficient lighting.

► Office buildings require much less heating energy than residential accommodation since the high user density and the electronic appliances cause considerable heat loads. These aspects were optimally incorporated in the new building for the **Centre for Environmentally Conscious Construction** in Kassel. The large-area thermal protection glazing combined with effective sun protection maximises the solar gains in winter and prevents overheating in summer. The base plate is thermally insulated on its upper surface and tube banks are set into the concrete so that the floor functions like a heat exchanger in summer and releases excess heat into the soil. The target final energy value of 70 kWh/m²a for heating and auxiliary power for the technical equipment in the building has more than been met and a value of 32 kWh/m² was achieved in 2003.

► Energy-efficient construction enables individual designs to be tailored to users' special requirements. This is shown by the EnBau project for a **sheltered workshop** in Lindenberg in the Allgäu region. The workshop provides a stimulating environment with large window areas, plenty of wood and attractive colour schemes. A heat pump, pellet boiler, and thermally active ceilings and floors ensure the workshop is kept warm and comfortable. A factory roadway enclosed by glass connects the workshop to the communal building and provides an optimum source of daylight. During the planning stage, an ecological and economic balance was drawn up for the entire life cycle of the workshop with the aid of an integral software program. The result was that the low energy requirements and the utilisation of renewable energies considerably relieve pressure on the environment. Above all, however, the roughly 140 disabled people, most of whom will spend their entire working life here, feel at home in the workshop – not least due to the simple, barrier-free orientation, the light and airy rooms, and the cosy atmosphere.

Future R&D topics

Significant progress has been made in the past fifteen years in the field of research and development for building components such as heat protection. This progress means that three-litre house standards can be economically implemented in modernised and new buildings. The long-term goal in EnOB is the "zero-energy building". This means that integrative R&D efforts will have to be continued, particularly in structural engineering and technical equipment in buildings, since only then will it be possible under central European climatic conditions to economically achieve an annual zero-energy balance for buildings.

Energy-efficient communities

Towns and local authorities are important actors in efforts for more energy efficiency. They decide on development plans and supply structures, they own numerous buildings and are shareholders in municipal utilities and housing associations. They take decisions on the expansion of district heat networks and on the role to be played by energy efficiency in the modernisation of public buildings. Although many local authorities in Germany are now concerned with climate protection and energy saving, practical progress still remains rather modest. This has less to do with a lack of technology or projects that are not economically ambitious. What is frequently lacking is quite simply specific knowledge about the most suitable measures to be applied locally. Furthermore, municipal utilities often only plan for a few years whereas energy efficiency requires long-term concepts.

The new funding concept for an "Energy-efficient Community" (EnEff:Stadt) introduced by BMWi in summer 2007 is intended to overcome these obstacles. The initiative deploys a wide range of existing instruments. Thus, for example, the combined generation of heat and power (CHP) and district heat, innovative insulation and waste heat recovery, intelligent control technology and modern information technology will be interlinked in such a way that energy-optimised construction and energy-related modernisation will be improved in whole neighbourhoods and districts of a town.

Experience gathered from the construction and modernisation of individual buildings provides an important basis for this work. VOLKSWOHNUNG in Karlsruhe, one of the largest municipal housing associations in the state of Baden-Württemberg, has, for example, renovated and modernised a large complex with 375 flats built in the seventies with the aid of funding from BMWi. "The consumption of heating energy was halved and CO_2 emissions reduced by about two thirds," said Dr. Reinhard Jank from VOLKSWOHNUNG. Moreover, surveys of the tenants have shown that modernisation considerably improved the amenities.

However, it is not easy to transfer such modernisation programmes to whole neighbourhoods. Residential accommodation, schools, commercial enterprises and office buildings all have different heating requirements and peak loads. Small manufacturers and traders often have higher energy base loads than residential buildings. "Furthermore, the greater the number of parties involved and the more disparate their needs, the more complex the projects become," says Jank. An energy-efficient community will therefore only become possible if all the players pull together. The Federal Government's new national energy efficiency action plan also emphasises that increasing energy efficiency is not a job for politicians alone. On the contrary, it is a task for the whole of society and depends on committed efforts from citizens, industry, the federal states and local authorities (www.eneff-stadt.info).

Efficiency in the grid

District heat is an important key to an energy-efficient town. It can be produced from fossil or renewable sources, from waste heat or via combined heat and power generation. However, district heat needs an extensive supply network which is associated with a high level of fixed costs. In the past, that was a clear disadvantage in comparison to individual heating systems. The case may be different in future. District heat is less sensitive to rising oil, coal and gas prices than

Power centre supplying coolant to Potsdamer Platz in Berlin (outside view of the building on p. 22).

other heat supply systems. BMWi assumes that the proportion of district heat in the heat supply – currently about 12 % in Germany – can be considerably increased using the Scandinavian model where there is a share of about 50 % district heat.

Transport and distribution account for up to 70 % of the costs of district heat to be borne by the customer. In order to extend the supply network outside the conurbations, it is therefore necessary to reduce the fixed costs associated with the network. As part of the funding concept for "Energy-efficient District Heat" (EnEff:Wärme), BMWi therefore intends to support projects that make the district heat supply more efficient and also more economic. There are plenty of starting points ranging from the optimisation of technologies for generating heat and air conditioning, improved heat exchanger systems, pipelines and installation techniques up to and including designs for novel supply networks.

Lower inlet temperatures, for example, lead to greater efficiency. New or modernised buildings have much lower heat requirements than older buildings. Inlet temperatures of considerably less than 70 °C are sufficient for these consumers – whereas most of the existing supply networks provide heat at 80 to 130 °C. A lower inlet temperature would make it easier to use waste heat or renewable energies. Demo projects will be funded as part of "EnEff:Wärme", which will combine the comprehensive modernisation of buildings and efficient heat networks to reduce primary energy consumption to such an extent that it is in the same order as that of low-energy or passive houses.

In rural regions, the number of users of district heat per unit area is much lower than in towns – a factor that leads to higher investments for each building connected to the grid. For this reason, in order to be economic, it is especially important to plan and implement low-cost supply systems. An inlet temperature of less than 70 °C does not only save primary energy but above all makes it possible to use cheap, flexible plastic pipes and thus increases the efficiency of combined heat and power units. In rural areas, it is also appropriate to make use of raw materials available locally such as waste or biogas. A comparison of various energy carriers conducted by the Fraunhofer Institute for Environmental, Safety and Energy Technology (UMSICHT) showed that in particular combined heat and power stations operating with biogas or natural gas are economically efficient for generat-

Control room of the GCC plant in the south of Munich. Efficiency is increased by a lower temperature level.

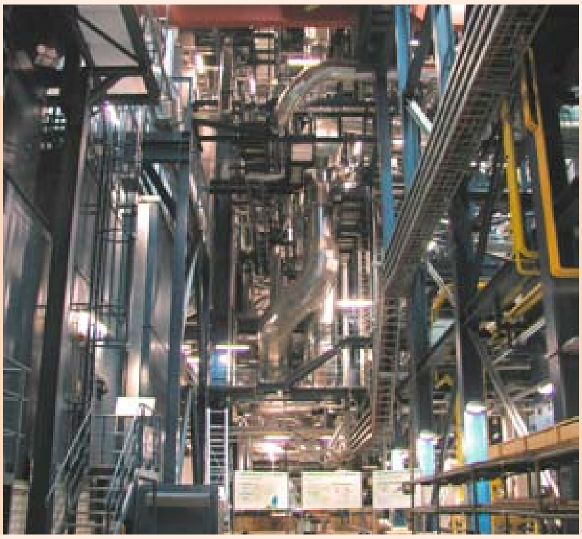
ing the base load – and even more so if the biogas can be obtained from slurry or plant residues. “In this way district heat can be produced at a final cost of significantly less than ten cents per kilowatt-hour,” said the UMSICHT expert Dr. Christian Dötsch.

Heat with water instead of steam

Steam is also still used as a heat-transfer medium in district heating networks. However, it involves a number of disadvantages: steam networks are expensive to repair and maintain, large heat losses occur because of the high operating temperatures, it is difficult and time-consuming to install the pipelines and so new connections are relatively expensive for the customers. Moreover, the high temperatures prevent an effective combined generation of heat and power and the inclusion of low-temperature heat from waste heat or biomass.

In Germany there are about one hundred steam networks with a total length of about 1300 km. One of the largest networks with a route length of 250 km and 4400 customers can be found in Munich. However, even in the past, the high steam temperatures of in part significantly more than 130 °C were usually superfluous. 95 % of all consumers connected to the grid require heating energy at a temperature level of less than 100 °C.

Lowering the inlet temperatures therefore not only makes sense but is also geared to market requirements. A BMWi research project in cooperation with the Munich municipal utilities has demonstrated that the energetically unfavourable steam can be replaced by hot water. Munich has been progressively converting the heat grid since 2003. The municipal utilities have thus been increasing the efficiency of their CHP plants since the steam in the turbines can be converted more efficiently into electricity than was previously the case. The new gas and steam turbine power plant (GCC) in the south of Munich generates about 160 gigawatt-hours more electricity per year now that the waste turbine heat is fed into the new hot water network. The project has furthermore also set new trends for local climate protection. The reduced energy use cuts down on elec-



The new GCC plant in the south of Munich generates over 160 gigawatt-hours more electricity per annum by feeding its waste turbine heat into the new hot water network instead of into a steam district heating grid (picture on the left).

tricity imports from the German grid with a CO_2 potential of more than 100,000 tonnes per year. The project has, not least, sent a clear message to other cities. Ulm, Kiel and Hamburg all intend to convert their heat grids to hot water.

Although district heating networks supply energy for heat and hot water, in summer they do not provide the necessary cold. Not so in Neubrandenburg. Since 2005, tests have been under way here investigating how effectively excess heat from a heating and power station (GCC) can be stored in summer in deep aquifers and then withdrawn again in winter. The aquifer storage system consists of two 1250-m-deep boreholes connected by a pipeline. In summer, thermal brine is withdrawn from the “cold” borehole and heated by the waste heat from the power plant. The heated brine is then injected into the second borehole. Deep underground, the temperature of the thermal water increases to 80 °C. In winter, water is withdrawn from the “hot” borehole and fed into the district heating networks. In the winters of 2005 and 2006 the storage scheme operated without difficulty. However, the evaluation shows that operation is not yet efficient enough. This is not the fault of the storage system itself but is due to the fact that it is extremely difficult to predict the actual requirements of the consumers connected to the system.

District heating networks can be tailored to consumers’ needs and at the same time operated economically, efficiently and in a climate-friendly manner. “Basically, energy with a very low exergy fraction is sufficient for heating and cooling,” says Dr. Christian Dötsch from the Fraunhofer UMSICHT Institute. With respect to district heat, this means the low-exergy principle (LowEX). Heating and power stations must convert primary energy into as much electricity as possible without great losses and the rest into useful heat.

What form novel district and local heat networks could take is the subject of an investigation being implemented by UMSICHT and funded by BMWi over the next few years. The investigation focuses on several questions: How can new housing developments be efficiently supplied with heat, cold and possibly also with electricity? Can modernised older buildings be integrated into existing district heating systems? What is the potential of additional secondary grids providing, for example, heating water in winter and cooling water in summer?

Twin pipelines, for instance, are very promising. These networks have separate pipelines for hot water for showers and cooler water for heating. Using the residual heat from the return flow for buildings that only have low heat requirements also promises to increase efficiency. Attention is always focused on high efficiency even if electricity and heat are to be generated from renewable energies. “Renewables are also limited,” adds Dötsch. After all, the areas of land available for wind energy converters, biomass or solar modules are always restricted.

Industry accounts for about one quarter of Germany's energy consumption. In many cases, the high energy requirements are due to the nature of the processes which often require temperatures of more than 1000 °C. An interview with Dr.-Ing. Frank Grote, managing director of Gustav Grimm Edelstahlwerke in Remscheid (right), and Dipl.-Ing. Wolfgang Bender, head of the department for the gas industry and industrial furnace technology at the VDEh-Betriebsforschungsinstitut (Institute for Applied Research and Development – BFI) in Düsseldorf.

"We are making natural gas savings of more than 30 %"

? What were the motives behind your company's decision to become involved in a research project on more efficient energy use?

Grote: Due to the rather high energy prices in this country, the steel industry has great interest in saving energy and it has already implemented a wide range of measures for more efficient energy use. We have good reason to assume that Germany is playing a pioneering role here – also from the international perspective. But the motivation for joining BMWi projects on research into energy efficiency goes far beyond such considerations of cost since it is clear that we must further reduce CO_2 emissions in order to protect the climate. We are concerned with precautions for the future since it is often the case that, for example, the economic benefits of a new development to be reaped in the short term are usually rather limited, while disturbances in the operational cycle due, for instance, to tests may even result in production losses.

Bender: Our institute collaborates closely with enterprises from the steel industry and also from other sectors. We have noticed again and again that the willingness of companies to communicate, even across the boundaries of the actual firm, and to address new developments cooperatively is generally tending to increase. In some subsectors, such as steel forging, the interest is really very great – even where issues of competition are involved. We are experiencing this once again in our KINAMI project. Here, together with a number of large and small companies in the forging sector, we are developing an innovative thermal regenerator/flat flame burner system in order to reduce both CO_2 emissions and also the operating costs of high-temperature furnaces. They are used to reheat slabs and blocks from the steelworks since in order for steel to be forged the material must first be reheated to about 1200 °C. With the novel regenerator/flat flame burner, which sucks the waste heat out of the furnace and feeds it into a ceramic storage system for interim storage, we have already succeeded in heating the combustion air to about 1000 °C in the opposite cycle both in a pilot plant and in actual operation. At the moment, 350 °C is state of the art.

? And how big is the associated energy-saving effect?

Bender: About 30 to 35 %.

Grote: That is a very positive result. We are convinced that our commitment to research will pay off. And we are also aware that these energy savings will reduce CO_2 emissions. We are very satisfied with this result.

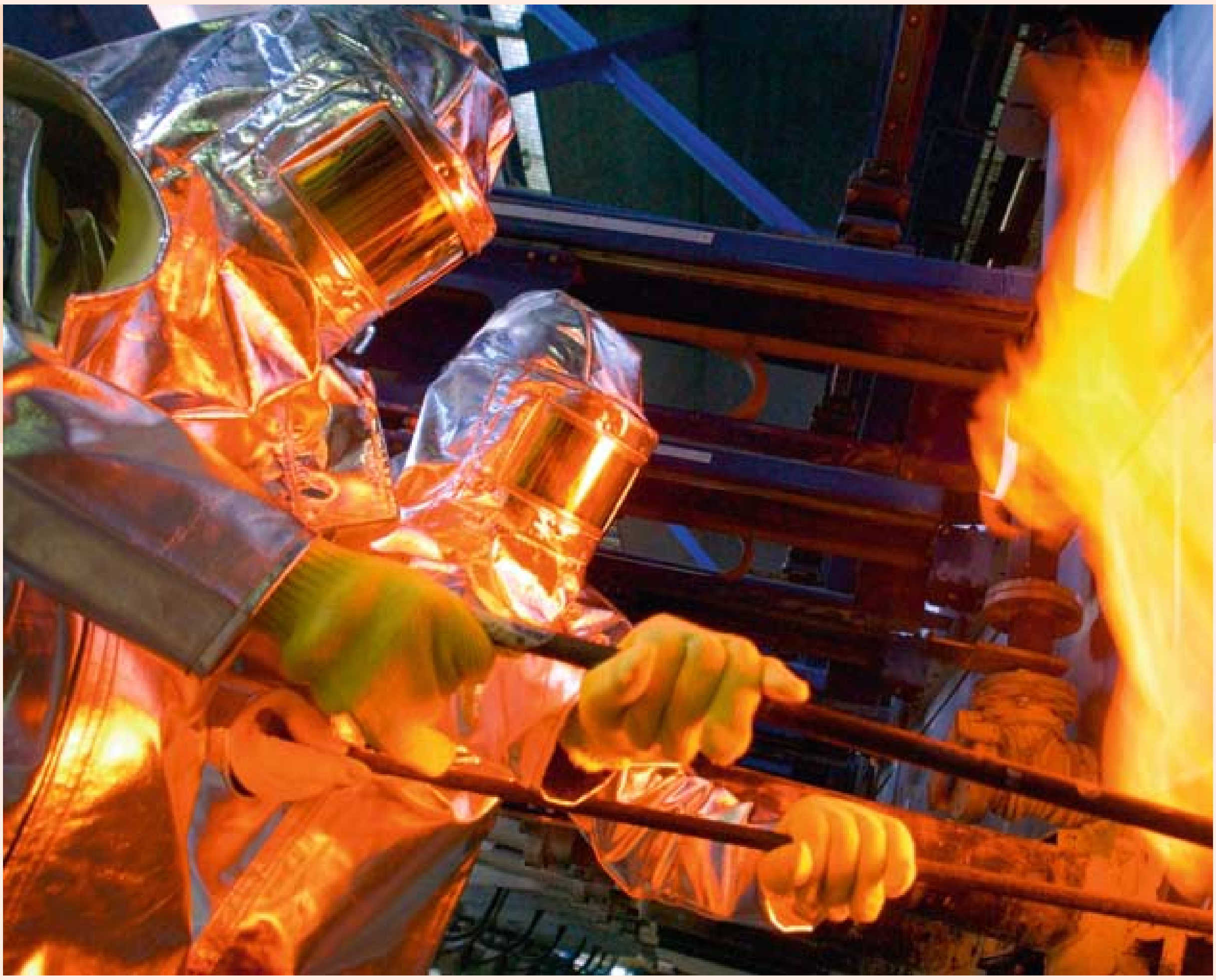
? How did you manage to achieve this innovative solution?

Bender: The idea that sparked it all off originated in a conversation at a conference and this gives some idea of the importance of communication in any innovation. Together with a company from the aluminium industry, we had already developed a similar but simpler regenerator at our institute. We were able to contribute our know-how from this development to the project with the steel industry.

Grote: We tested the new development under realistic conditions in a production environment. Naturally we had a few teething problems. Further tests in other companies with slightly different requirements are on the agenda so that ultimately our sector will have an energy-saving regenerator/burner system at its disposal. By the way, the new development is not only outstanding from the aspects of economic efficiency and climate protection, but it was also found that the new burner distributes heat in the furnace and transfers it to the steel in a very much more uniform manner.

Bender: This brings about an enormous improvement in quality since tiny temperature fluctuations can have a negative impact even at such high temperatures. This is a spin-off from this project which we will undoubtedly wish to employ in other sectors. If you like, you could say that this has sown the seed for a new research project.

Energy efficiency in industry, commerce, trade and services



In the glass industry, depending on the type of glass and the material composition, the fusion temperature is between 1000 and 1600 °C. New insulating materials can reduce the heat losses from the furnaces.

A start has already been made. In the past 30 years, the energy and raw material efficiency in industry has increased significantly. Production plants have been continuously replaced and processes optimised. Many sectors have undergone considerable change. However, the unexploited savings potential is still high. The figures speak for themselves. More than 40 % of the final energy required in Germany is accounted for by the sectors of industry, commerce, trade and services.

In manufacturing and commercial enterprises, space heat alone is the biggest item on the energy bill accounting for about 46 %. In industrial enterprises, process heat represents the biggest percentage of final energy consumption with about 65 %.

The twofold challenge: saving energy and improving quality

If companies decide to save energy, then they do not only protect the environment but also save operating costs. However, experience shows that in industry the willingness to apply energy-saving measures is not simply a matter of saving pennies. Management can frequently only be convinced if there is a chance that they could gain additional benefits from restructuring. This may be improved product quality, increased operational reliability or optimised production operations. Sometimes it is simply an increase in prestige that tips the scales in favour of a technical reorientation. One thing is certain – without investment in efficient energy use, future-oriented corporate strategies can no longer be developed in this day and age. Successful practical examples and application-oriented know-how are required in order to convince top management. If something has proved its worth elsewhere then executives are more likely to implement it in their own company.

In many cases, the engineers' perspective has changed. Due to technical progress, the energy requirements of many individual processes have already approached their physical limits so that room for improvement is now very restricted. A holistic perspective must be adopted instead. Engineers do not just look for new materials and innovative processes for energy savings but research increasingly focuses on the entire process chain. Established processes must be re-examined and individual processes linked more effectively. In this context, neural networks are playing an increasingly important role. They help to control production processes via model calculations to make them more energy-efficient.

Work in the research and development departments pays off. This is also shown by the results of projects funded by BMWi. Many of the new or further developed technologies are now available commercially and have made their way onto the market. Due to the high proportion of exports they make a global contribution to improving the energy efficiency and environmental compatibility of industrial production processes.

The distribution of government funding is guided by consumption priorities. Funding projects concerned with the improved utilisation of process heat are currently increasing in significance. This concept comprises all forms of heat used in industrial or commercial processes, whether in a car wash or a cement kiln. There is an enormous savings potential. In high-temperature processes in the ceramic industry alone, more than 40 % of the heat generated at high energetic expense is lost as waste heat.

Research priorities

Resources should be used wisely. This is also true of mass materials that devour huge amounts of energy for their production. In Germany alone, far more than

In the ceramic industry, some kilns reach temperatures of more than 1800 °C.

40 million tonnes of steel, far more than 30 million tonnes of cement and about 20 million tonnes of paper are produced each year. In order to reduce the material throughput and energy consumption in industry, the cycles of production, utilisation, disposal and reuse must be closed more effectively. The efficient use of materials is therefore also one of the new priorities in research funding. In many cases, there is still considerable need for development. We are not yet at the end of the road.

Many industrial products literally undergo a baptism of fire during fabrication. The temperatures such materials have to withstand are extremely high. In the ceramics industry, for example, the kilns are heated to more than 1800 °C. The higher the temperatures, the greater the heat losses. One possibility of reducing waste heat is to use more efficient insulating materials. However, the materials used in the past – conventional lightweight refractory bricks or ceramic fibre products – have their limitations. Lightweight refractory bricks are only suitable for temperatures of up to about 1100 °C and fibre materials are regarded as carcinogenic and their handling requires elaborate processing and protective measures.

Converter gas is a by-product arising during steel production. The improved energy-related use of such process gases, for example to heat firing furnaces, is the subject of ongoing research work.

High-temperature insulating materials

However, there are alternatives. In a collaborative project funded by BMWi and headed by the German Institute for Refractories and Ceramics (DIFK) in Bonn, researchers developed new high-temperature insulating materials on the basis of calcium hexaaluminate. The microporous materials have excellent thermal insulating properties, can withstand temperature cycling well and are resistant to chemical loads. Practical trials have proved successful. For example, if the conventional lightweight components used in the roof of a walking-beam furnace were replaced by innovative insulating materials, then 30 to 35 % of the energy could be saved. A further bonus is that the heavy-duty materials do not represent a health risk and can be disposed of without difficulty as required.

The newly developed insulating materials can be applied not only in the ceramics and steel sectors but also in the glass industry, the chemical industry as well as in cement works and refuse incineration. Germany alone consumes more than 100,000 tonnes of high-temperature insulating materials each year.

Rotary regenerator

Reducing waste heat losses is one strategy for cutting energy consumption in a production process. The second strategy consists of using the resulting waste heat to preheat the combustion air. There are two proven systems. In the case of recuperators, waste gas and fuel gas flow into the plant simultaneously – usually in a counterflow. The combustion air can be heated up to a temperature of 600 °C. If higher temperatures are required then regenerators are called upon. In these heat exchangers, heat is transmitted by interim storage of the energy in a thermal mass.

Conventional regenerator/burner systems consist of several storage systems that are alternately ther-

The steel industry is a pioneer in the use of novel burners. On the left, a ceramic heating tube in an experimental laboratory. Ceramic burners are much more resistant to high temperatures than steel burners. These burners enable natural gas firing to be used economically in high-temperature processes which at present depend on electric energy. On the right, an annealing furnace fired by hundreds of ceramic FLOX burners.

mally loaded and unloaded. This switching causes the temperatures of the combustion air and flame to fluctuate. Not all industrial processes can cope with these unstable conditions. Another disadvantage is that the technical design of the conventional systems only has limited scope for innovations to reduce pollutant emissions.

Modern rotary regenerators take a different approach. Inside these facilities, the combustion air is heated and at the same time the waste gas is cooled so that the temperature of the combustion air remains constant. To date, they have only been applied for heat exchange at low and medium temperatures, for instance in air conditioning equipment. In a research project funded by BMWi, the operating principle has been extended for the first time to include high-temperature processes of up to 1200 °C and optimised so that it is ready for application.

There are a large number of possible applications for the newly developed system consisting of rotary regenerator and burner ranging from heat treatment furnaces for iron and steel up to and including smelting furnaces for aluminium and glass as well as kilns for ceramics. In the steel industry, the system may, for example, replace the conventional ladle heaters that heat the casting and transfer ladles for pig iron and steel. The energy savings are enormous. Investigations at a heating stand for steel ladles in an electric steel mill showed that the new technology could cut the consumption of natural gas by 45 %. But it is not only energy savings that are attractive for the companies. Rotary regenerator and burner systems offer a number of practical advantages with respect to firing that contribute towards optimising the process flow.

FLOX

The reduction of pollutant emissions in high-temperature processes is one of the greatest challenges in industry and is one of the engineers' top priorities. However, sometimes it is mere chance that puts them on the right track in their development work. This was the case when nearly twenty years ago, researchers noticed to their surprise in tests on a recuperator burner that the instrument monitoring the burner flame suddenly ceased to display a signal. The noise of the flame had also disappeared. Nevertheless, the fuel was still completely burned. The researchers christened the phenomenon flameless oxidation (FLOX). What is unusual about FLOX is that hardly any harmful nitrogen oxides are formed. It is thus possible to preheat the combustion air to high temperatures thus enabling great energy savings. In further experiments in a project funded by BMWi, scientists explored the conditions that would make such a process suitable for industrial applications. In the mean-time, a wide selection of FLOX burners are now proving their worth in industry. “However, the potential of the technology has by no means been fully exploited,” says Dr. Joachim G. Wünning, managing director of WS Wärmeprozesstechnik GmbH in Renningen, which has successfully implemented the low-emission combustion principle and is continuously further developing it.

A promising field of application is, for example, the combustion of lean gases such as biogas, wood gas or landfill gas. In comparison to natural gas, lean gases have a lower energy content and contain more nitrogenous compounds so that the quality of the fuel fluctuates.

“Conventional burners have difficulty coping with these conditions,” says Wünning. “FLOX burners can deal with the challenges better and the combustion is cleaner.”

Utilisation of process gas

A not inconsiderable proportion of the energy used in industrial processes remains in gaseous by-products such as top gas, producer gas and refinery gas. It would be well worthwhile to make thermal use of these process gases since their energy content corresponds to one sixth of the natural gas consumed in Germany. However, it is difficult to apply this is practice since, among other aspects, the low calorific value of the gases as well as impurities can lead to malfunctions. In several projects funded by BMWi, researchers of the Operational Research Institute (BFI) in Düsseldorf are working on innovative processes in order to better control the process conditions during combustion of the gases and to remove undesirable accompanying substances. One of the first successes is a reactor filled with activated charcoal or activated coke that separates the process gases from the gas flow. Its low selectivity means that the range of adsorbed impurities is unusually broad. Another bonus is that the reactor has a long operational life and low operating and maintenance costs. The impact of optimised process gas control has a favourable effect on the energy balance. In many heat engineering plants, energy savings can amount to as much as 10 %.

Energy-efficient recycling

Improved control of process conditions can also increase energy efficiency in the recycling of residual materials. The recycling of residues containing iron, such as washing tower sludge or rolling mill scale, has a great potential since the German steel industry produces several 100,000 tonnes of this waste each year. Useful new materials can be obtained from these valuable secondary raw materials in the blast furnaces of the steel industry. Since the composition of these residual materials varies, recycling processes in conventional blast furnaces and sintering plants are very complex and lead to an increase of more than 50 % in fuel requirements. To date, above all human skills have been called for in such complicated process control. Individual decisions on the part of the operating team require a high degree of expertise and experience to ensure that the production processes are properly controlled.

In order to help staff make the right decisions, BFI together with DK Recycling und Roheisen GmbH is developing a computer-aided system that can continuously analyse the process in the sintering plant and blast furnace and suggest appropriate courses of action to the operating personnel. The control system funded by BMWi has already successfully passed its practical test. It was put into permanent operation for recycling residual materials containing iron in sintering plants and blast furnaces leading to a 10 % reduction in energy consumption. An economically significant side effect is that the metallurgical composition of the pig iron can be flexibly adapted to prevailing conditions with the aid of the modular software program – thus increasing product quality.

REMIS

Mass-produced plastic articles are mainly manufactured by injection moulding. The products range from plastic articles weighing 50 kilograms down to tiny components just a few milligrams in weight. High demands are made on quality. If even the slightest divergence is discovered then the injection moulded piece is simply rejected. In this case as well, production processes can be optimised using computer-aided control systems. The REMIS collabora-

In the blast furnaces of the steel industry, valuable materials can be obtained from secondary raw materials containing iron, such as washing tower sludge or rolling mill scale.

tive project (rational energy savings and minimisation of material requirements for injection moulding) focuses, for example, on "neural networks" – a kind of information processing increasingly used in recent years. These artificial systems inspired by neurology are self-adaptive, fault-tolerant and also capable of incorporating unclear information. In order to "train" the software, before production begins tests are performed with various machine settings. From these experimental data, the neural network "learns" the relation between product quality and characteristic process parameters such as temperature and rise in pressure. The results show that the forecasts are highly reliable. According to the first assessments by experts, rejects in the plastics industry can be cut by half with the assistance of REMIS. Energy consumption would drop by about 15 %.

High quality is demanded of injection-moulded products in the plastics industry. Even the smallest deviations frequently make the product unusable. A BMWi research project demonstrated that these production processes can be optimised with the aid of modern software based on neural networks.

Low-energy separation

In many industrial processes, the separation of material mixes is all part of a day's work whether in the recycling of waste material, the drying of products, the production of chlorine by electrolysis or the decontamination of waste water. Traditional separation processes such as distillation involve a high consumption of energy and are very expensive. If mixtures cannot be completely separated then this leads to increased recycling costs. As part of a research project funded by BMWi, scientists at Henkel KGaA, Düsseldorf, further developed a process that separates substances by means of a magnetic field.

The basic principle is simple. A carrier liquid with finely dispersed nanoparticles, a so-called ferrofluid, is added to a mixture of substances. The surface of the magnetic particles is changed in such a way that they selectively attach themselves to the substances to be separated. The labelled substances can be separated by applying a strong magnetic field. The labelling particles are subsequently removed and can be purified and used again.

This trick has already proved useful in molecular biology for separating viruses, bacteria and DNA molecules, but it has not yet been applied on an industrial scale. This deficiency has now been remedied. For example, researchers succeeded in cleaning waste water polluted with nickel so thoroughly by using magnetised fly ash that no heavy metals could be detected. This level of purification cannot be achieved by conventional procedures. The technology has to be further developed before ferrofluids can be applied on a commercial scale. The particles must, for example, be stable in the long term, environmentally friendly and cheap to produce.

Heat pumps and refrigeration technology

Another research priority is the field of refrigeration technology and heat pumps. The chlorofluorocarbons (CFCs) previously used as refrigerants deplete the ozone in the stratosphere. After the Montreal Protocol and the German directive banning CFCs and halons, the directive on substances that deplete the ozone layer now regulates measures reducing emissions and improves the tightness of old refrigeration systems – ozone-depleting substances are no longer permitted in new systems. Many refrigerants moreover contribute to global warming. The aim was to replace these substances with environmentally friendly and energy-efficient alternatives and to develop appropriately adapted cooling units and heat pumps – such as CO_2 refrigerating machines with expanders, CO_2 heat pumps and zeolite adsorption heat pumps as well as compression heat pumps with improved circuits. Attention was furthermore focused on steam-jet refrigeration machines as well as improved technology for combined heat and power generation.

Current projects are concerned with low- and medium-power absorption and adsorption refrigeration plants, refrigerating plants driven by solar power and waste heat, as well as energy-efficient installations for use in supermarkets. There is still room for improvement with respect to optimisation of the overall process of producing and applying cold, which will lead to further research work.

Innovations in the steel industry

Steel is a material with a long tradition. But this doesn't mean it's on the scrap heap – on the contrary! Steel has developed into a real high-tech product. There is a steadily growing demand for steel on the world market. In recent years, a new class of steel materials have made a name for themselves: the so-called high-strength and ductility (HSD) steels. HSD steels are extraordinarily ductile, can be easily shaped and display extremely high strength. These material properties are especially attractive for the automobile industry. The more ductile the material, the more it can be deformed before it ruptures. In this way, car body panels can be shaped more easily in the press. The finished vehicles are lighter and more energy-efficient. The construction of intelligent crumple zones is also conceivable. After impact, the material is first deformable, but then in a fraction of a second it is transformed into a harder structure and thus protects the passengers.

These high-tech panels are not yet fabricated on an industrial scale since the melt is less viscous and difficult to work using conventional steel working processes. This problem can be solved by the application of a new strip casting process – known as direct strip casting (DSC). In a cooperative project involving Salzgitter Mannesmann Forschung GmbH, Clausthal University of Technology and Max Planck Institute of Iron Research, researchers have developed a pilot plant for manufacturing HSD lightweight steels by the DSC process. Since the plant design is very compact, some energy-intensive steps can be dispensed with in this technology so that the DSC process can make do with just 25 % of the energy otherwise required. Moreover, it can tolerate high proportions of scrap. The production process has already reached such an advanced stage of development that we may see the first cars with components made of HSD steel on the road by 2010.

Expert knowledge for product development

The factors of "time" and "information" play an important part in the development of new products. Developers spend a not inconsiderable proportion of their time acquiring and evaluating information. In doing so, experts now frequently make use of the Internet. The available data material is often incomplete and confusing so that further searches are then required. The pressure of competition additionally shortens the development times. Innovations thus threaten to fall prey to the pressure of time. As part of the "E2ProNet" project funded by BMWi, researchers have developed the Internet platform LCE Guide (www.lce-guide.de), which provides comprehensive information on innovative materials and technologies. The target groups are manufacturers and product developers from the electrical and automobile industry as well as from other sectors. The difference from other databases is that the knowledge database has a modular structure and provides a wide range of documents and specific information. The database is undergoing extensive operational tests. Researchers from KERP Centre of Excellence Electronics and Environment in Vienna have already developed a computer "ecomouse" with the aid of the LCE Guide. The cordless optical mouse does not need batteries and is powered by an alternative energy supply based on double-layer capacitors and a special circuit.

A furnace for producing electric steel easily consumes as much electricity as a small town. Furnaces operating on the foamed slag principle can reduce specific energy consumption by about 5 %.

Innovations can also be found in other sectors of the steel industry. The term “steel” itself describes more than 2,200 varieties which differ in their alloys and material properties. Stainless steel accounts for about 19 % of steel production in Germany. One of the techniques for producing steel is the melting of steel scrap with the aid of electric current. In order to make this more efficient, engineers apply what is known as the foamed slag process. Foaming agents such as carbon or oxygen produce a layer of slag foam on the surface of the molten steel, which functions like an insulating layer and reduces the energy requirements. This process did not previously function with stainless steel with a high chromium content since the slag was too rigid and slow to react. With BMWi funding, researchers from BFI in cooperation with industrial partners have now developed a variant of the foamed slag process, which amongst other aspects includes the injection of coal. This method has potential. In this way, electricity consumption required for the production of stainless steel can be reduced by about 5 %.

Outlook

Future priorities for BMWi funding in the field of efficient energy use in industry, commerce, trade and services will include high-temperature superconductors, innovative engine development for stationary applications, demand-side management, intelligent network, measuring and control services, as well as the fabrication and application of lightweight materials such as ultra-high-strength steels and the research topics of material efficiency and energy-efficient recycling.

Efficient energy use and storage

The German electricity market has undergone a radical change in the past few years. Deregulation on a European level has led to an opening of the grids and for the first time has initiated competition amongst the electricity utilities. It is therefore now possible for consumers to have a free choice of supplier. The supply scene has also changed its appearance. Since 2000, the Renewable Energy Resources Act has obliged grid operators to purchase electricity from renewable sources and to pay a fixed rate for it. This has greatly encouraged the generation of electricity by solar and wind power and biomass. Ambitious European targets for climate protection and trading with CO_2 certificates will continue to promote the expansion of renewable energies in future. Furthermore, due to the burgeoning number of photovoltaic plants, wind parks and combined heat and power facilities which, as a rule, generate electricity in a decentralised manner, the number of providers involved in the energy market is increasing.

Electric grids of the future

Today, Germany has a stable electric grid. Every citizen and every company benefits from the advantages of high security of supply. Nevertheless, the existing grid structures are facing an enormous technological change. Due to increasing decentralisation on the supply side and rising expectations with respect to more efficient transmission and distribution of electrical energy, ever greater demands are being made on the flexibility and capacity of the entire grid structure. At the same time, this should not result in any additional adverse effects on the safety or reliability of the electricity supply. It is expected that these altered conditions will in future lead to completely new grid configurations.

The latest technological developments, for example, in the field of modern information and communications technology (ICT) gives suppliers and grid operators considerable opportunities for new supply models, which can be related to the concept of "smart grids". As an example we can mention the concept of a "virtual power station" – which means linking a number of small decentralised electricity suppliers to form a network with a common control system. The rapidly developing ICT opens up great potential for innovation in the transmission, distribution and utilisation of electricity. To this end, BMWi has launched the funding competition "E-Energy:ICT-based Energy System of the Future" as part of its funding of multimedia research.

Other innovations such as those in materials development or electronics and the latest findings from basic research can be taken up for the selective further development of intelligent network structures. In this way, the latest developments in the field of high-temperature superconductors (HTSCs) represent a promising approach for low-loss, i.e. efficient, power transmission. Another important aspect in the development of modern electricity supply structures is that electric power is beginning to be used for individual mobility. Hybrid plug-in vehicles and vehicles powered purely by electricity are available on the market or are being developed and tested. This leads to additional markets for electric energy and in the long term also to opportunities for regulating the grid. At the same time, this should be seen in connection with the increasing feeding of energy from fluctuating sources, such as offshore wind energy converters, into the grid. As part of the Federal Government's Integrated Energy and Climate Programme (IEKP), efforts are being considerably extended to consolidate the research, development and testing of hybrid and electric vehicles. Four federal ministries – Economics and Technology (BMWi), Transport, Building and Urban Affairs (BMVS), Environment (BMU), and Education and Research (BMBF) – are collaborating in the implementation of these measures.

Storage for regulating the grid

The expansion of renewable energy technologies means that the proportion of electricity fed into the grid from fluctuating sources has increased considerably. Wind energy converters thus already cover more than 6% of Germany's electricity requirements. However, wind power can only be harvested when the wind blows. This is often not the case during periods when electricity demand is particularly high. The storage of electricity is therefore particularly important here. At the moment, **pumped storage power**

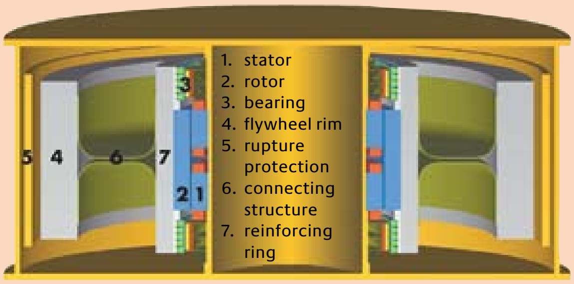
plants are very widespread. They take up the cheap electricity that is generated at night in base load power plants and convert it into potential energy by pumping up water. During the day when peak loads occur, the stored water drives the turbines and generates electrical energy once again. Pumped storage power plants thus make a considerable contribution towards controlling the grids and can be operated economically since the power can be sold during peak power periods at a much higher price than the cost of generating it at night. The problem of the discrepancy between supply and demand will become more acute due to the increased use of offshore wind energy converters. Geological conditions in Germany mean that opportunities for the construction of further pumped storage power plants are very limited. There is therefore considerable need for the development of other technologies that are suitable for storing electricity on a large scale.

Compressed air energy storage plants offer potentially high capacities for the interim storage of electricity from wind energy converters. In these facilities, air is greatly compressed by electricity and then stored, for example, in salt domes. When required the compressed air generates electricity again via a gas turbine. By exploiting compressed air, there is no need to use any energy to compress the air for the gas turbine process. The first compressed air energy storage power plant in the world was put into operation in Huntorf, in the north of Germany, back in the late seventies. The energy stored there can be released with an output of about 320 megawatts over a period of two hours. Adiabatic compressed air storage power plants represent a further development of the principle. They do not merely store compressed air but also the heat that is released when the air is compressed. However, this development is still in its early stages since almost all components – heat reservoirs, compressors, gas turbines – have to be redesigned. In general, it can be said that storage power plants cannot cover the entire energy demand but they are capable of making a significant contribution to reducing peak loads and thus the need to additionally expand the grid capacity.

Although possibilities for storing electric energy are available in the cases mentioned above this should not obscure the fact that these technologies still need a considerable amount of development. On the basis of quite different physical and chemical phenomena, researchers are seeking innovative solutions for the storage of electric energy. In doing so, they must always keep in mind that each application makes specific demands on the storage system.

The continuous further development of storage systems for electric energy is encouraged by yet another important aspect. Small grid disturbances hardly perceptible in private households can lead to immense economic damage for sensitive consumers (industrial processes, computing centres, etc.). By the interim storage of electricity at the consumer's site and by withdrawing electricity from the interim store in case of a disturbance it is possible to compensate for grid irregularities. In order to overcome grid disturbances, use can be made of **flywheel energy storage systems** that function as short-term storage systems. Industrial plants, for example, make use of this technology to avoid disturbances in production. Furthermore, flywheel storage systems in electric grids with a high proportion of decentralised energy generators ensure higher stability since they can compensate for fluctuating feed rates with peak loads in the range of several hundred kilowatts per second or minute. This technology therefore does not only benefit consumers but also grid operators. Although flywheel storage systems do not have high storage capacities they can release high quantities of electricity in a short time – which means that a very high output can be made available, as is important for sensitive production machines or consumers with short-lived but high peak loads. For example, trams or suburban rail networks can make use of braking energy for their next start from these storage systems. In the "Dynastore" project funded by BMWi, a light, compact flywheel storage system was developed for flexible deployment. The annular flywheel consists of a special carbon-fibre composite and the rim of the flywheel rotates in bearings with a permanent magnet and a specially developed high-temperature (HT) superconductor. The HT superconductor permits the flywheel mass to be supported in a non-contacting manner so that even at high rotational speeds only slight friction losses occur.

Superconducting magnetic energy storage (**SMES**) systems store direct current in a magnetic



Model of "Dynastore": new-generation flywheel energy storage systems will be ready for application in a few years in order to kinetically store electricity.

field generated by a superconducting coil. SMES systems are very efficient and hardly any energy is lost during storage. On the other hand, cooling the coil requires a good deal of energy and high-temperature superconductors are still expensive. In a first step, SMES is therefore appropriate for the short-term storage of energy.

Storage systems for transportation

Apart from the need described above to store electricity for regulating the grid, there is an increasing demand in Germany for efficient electricity storage in motor vehicles. In hybrid cars, for example, part of the energy generated by the engine is stored as energy on board the vehicle and is released again during the start-up process. This concept also offers the opportunity of using and storing braking energy. These vehicles are expected to operate more efficiently thus enabling savings in fuel consumption.

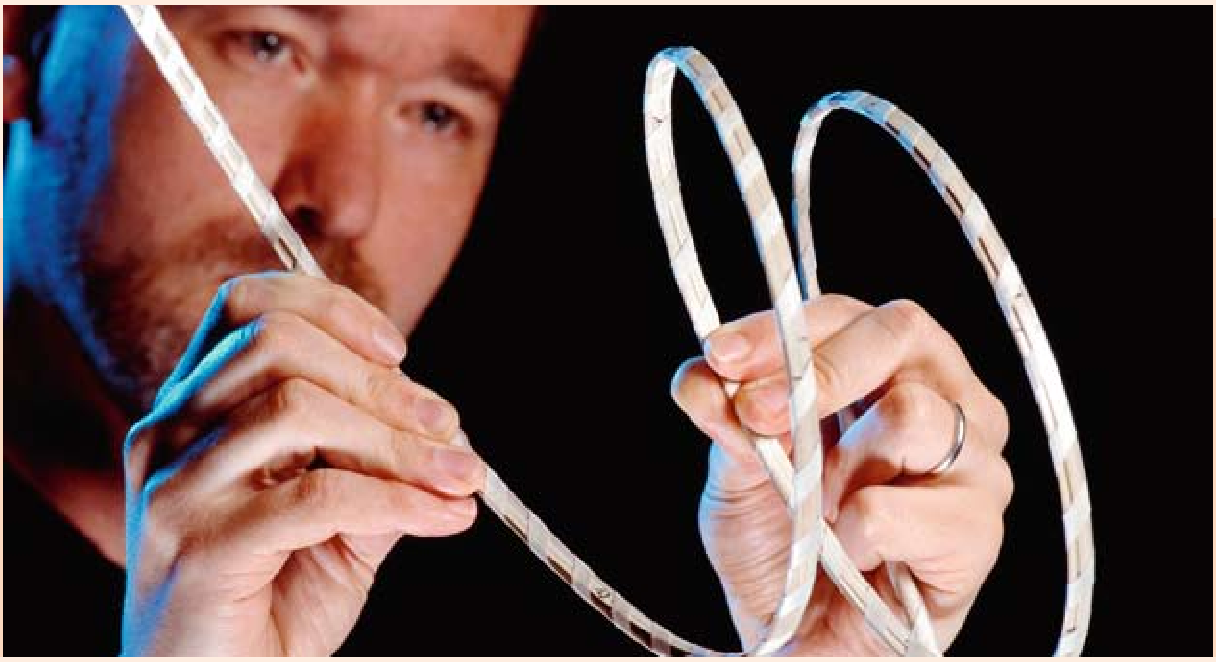
Supercapacitors (so-called **supercaps**) have a particularly high power density. Due to their long lifetime such double-layer capacitors are suitable as a replacement for conventional batteries whenever high reliability is required in connection with frequent charging and discharging. In comparison to batteries, supercaps can be recharged much faster and thus improve the availability of the appliances. Another advantage in comparison to other storage systems is the much simpler charging process. A particularly interesting example of the use of supercaps is in hybrid vehicles. In such applications, they can help to save energy in combination with an internal combustion engine and a battery. While supercaps improve vehicle acceleration, the battery makes a contribution towards reducing fuel consumption. In the next step, efforts would be made to replace the combustion engine by a fuel cell.

Electrochemical storage

Electrochemical storage systems such as batteries or accumulators are already used in a wide range of applications, for example in computers, torches or starter batteries, large numbers of which are produced for the automobile industry. However, there is still a need for considerable investment in technological development since some of the existing battery systems are too large or too heavy for the envisaged applications in cars or electric grids. They will also have to be designed so that they become less expensive, more efficient and even safer than they already are.

There are different criteria for electrochemical storage systems in the two fields of application. In the mobile sector, it is vital that the battery weighs as little as possible, whereas for stationary applications the weight tends to be less significant. In contrast, for stationary applications a high storage capacity at a reasonable cost is required.

For both fields of application, electrochemical storage systems based on **lithium-ion batteries** are regarded as a promising technological alternative to established battery technologies. Their decisive advantage is a very much higher storage density, and they also have great development potential. Lithium-ion batteries are already used today in a wide range of small appliances with low energy requirements such as watches or mobile phones. A great deal of research and development work is still required before they can be used economically in cars or the electric grid. The opportunities for improvement range from the application of new materials up to and including simplified fabrication



Superconducting wire windings increase the power density of engines.

in order to reduce manufacturing costs and increase safety for the user. This research is certainly worthwhile since ultimately only a lithium-ion system with a very high standard of safety is appropriate for use in hybrid and electric vehicles.

Outlook

Electric storage systems will play a decisive role in the future electricity supply scene. In preparation for its new funding concept **"Electric Grids of the Future"**, BMWi will be conducting discussions with experts on drawing up a research and development plan. In connection with the funding concept for "Electricity Storage Systems" that is already in progress, the increasing demand for systems for storing electrical energy in electric grids and automobile technology will represent another priority. Particular attention will be paid to lithium-ion batteries. Research will concentrate on increasing their storage capacity and their cycle stability. However, other storage technologies such as compressed air storage will also be included in the new support measure. Funding for innovative technological developments will aim to reduce costs in order to achieve or improve the economic viability of the product. At the same time, the concept will remain open for basic research in order to be able to respond rapidly to new know-how and promising concepts and processes.

BMWi does not only intend to pursue its activities on storage and grids as part of the measures on electromobility within the framework of the Federal Government's Integrated Energy and Climate Programme (IEKP), but also intends to perform systems analysis studies on the opportunities and limitations of electricity-based mobility by means of plug-in hybrid and electric vehicles. The studies will focus on the analysis and evaluation of impacts of the electric storage systems in vehicles on load flows, grid stability and the performance of both renewable and conventional electricity generating structures. The first results are expected in 2009. These studies may lead to the identification of options for action with respect to restructuring and expanding the grid, integrating renewable energies, and the use of intelligent counting and communications technology, as well as specific proposals for further research and development measures.

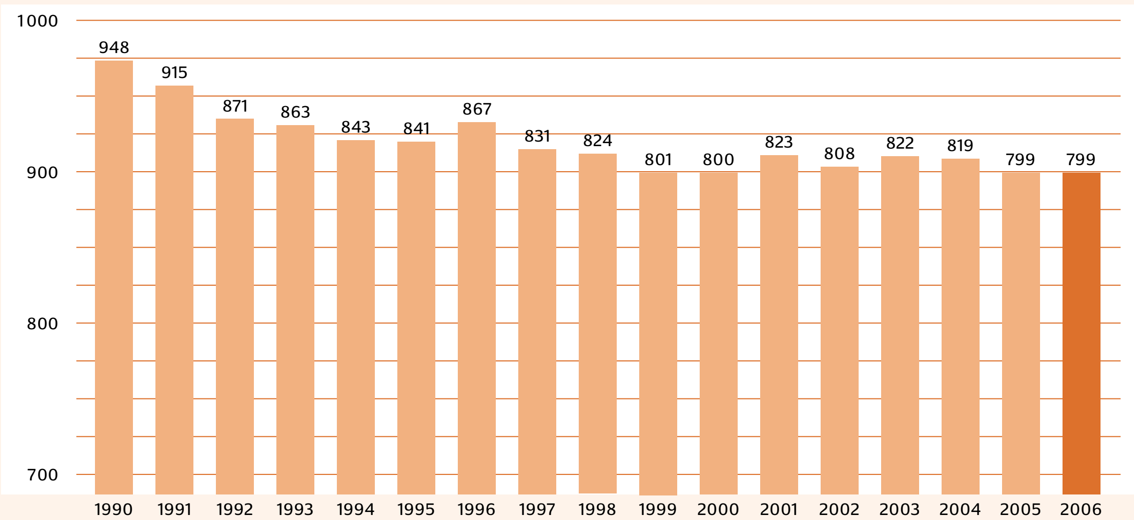
Superconductors

When electricity flows the cables usually become warm. This is not the case with superconductors. They transport electricity almost without loss. The energy industry has particularly high hopes of high-temperature (HT) superconductors which only need to be cooled by liquid nitrogen in order to transport electricity without loss. HT superconductors can increase the efficiency of electricity generation, transport and consumption, especially if high output is required. They can be manufactured from readily available materials and are usually ceramic-like compounds which are not toxic for man or the environment. For example, superconducting current limiters could replace choke coils and make transformers redundant. They protect the grid against overloading and short circuits. Other fields of application include engines, generators and induction furnaces.

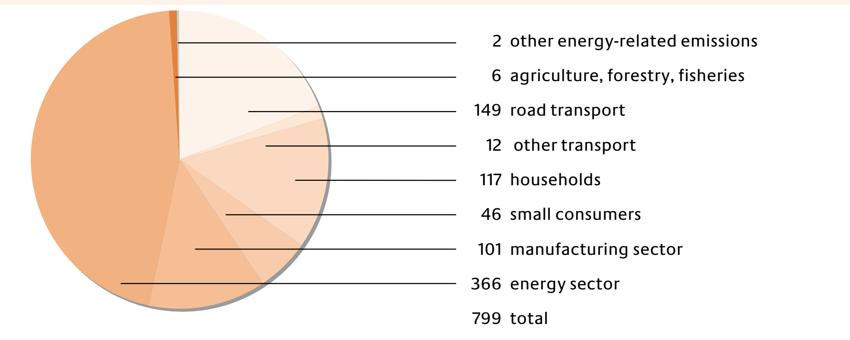
Efficient energy conversion

Fuel cells are considered a key technology for a sustainable energy supply and are therefore the focus of energy research and development. The way they work is just as simple as it is ingenious: the fusion of hydrogen and oxygen leads to the generation of electricity and heat in one single step. However, 60 % of the electricity used in Germany today is still produced in power plants run on lignite, hard coal, natural gas or oil – in other words with fossil energy carriers. The most important thing here is to improve the efficiency in order to save fuel and avoid CO_2 emissions.

Energy-related carbon dioxide emissions (Germany 1990-2006) in millions of tonnes



Energy-related carbon dioxide emissions (Germany 2006) in millions of tonnes shown by sector



BMWi/UBA, as of 08.07.2008

When fossil energy carriers are burnt, the greenhouse gas carbon dioxide (CO_2) is released. According to the accepted scientific opinion, the increasing concentration of CO_2 and other trace gases in the atmosphere is contributing to the amplification of the greenhouse effect and therefore to global warming. The conservation of resources and climate protection must therefore be taken into account by energy-policy measures, which will see efficient energy conversion and the prevention of CO_2 emissions becoming extremely important in this regard.

Fuel cells – all-rounders for a variety of applications – convert energy in an efficient and environmentally friendly manner. Although still in their infancy, research on fuel cells is progressing with giant strides. An interview with Prof. Dr. Werner Tillmetz, Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW), Ulm.

"Fuel cells are an attractive alternative"

? Where do you see the key advantages of fuel cells compared to other technological systems?

! They have two basic advantages. On the one hand, fuel cells have a much higher efficiency than internal combustion engines. Take the following as an example. The car that we drove to work in early this morning has an efficiency of around 20 %. This means that 80 % of the energy contained in the expensive motor fuel is blown out into the environment as hot air. The fuel cell drive systems that exist today are already capable of achieving an efficiency that is twice as high as this.

The second issue is that of zero emissions. The driving force, which has for example prompted the car industry for years to concentrate their efforts on developing fuel cells for car drives, is the zero emission legislation in California. The aim of this programme is zero-emission traffic – in other words, no particles, no nitrogen oxides, no pollutants at all.

In addition, there is the issue of how the energy supply can be diversified for transport in future. How can it be built on a broader and more independent fuel basis? At the moment, there is still a monopoly on crude oil worldwide. However, the resources are slowly running out and alternatives are urgently required. The most attractive alternatives in my opinion at the moment, particularly for mobile applications, are hydrogen and fuel cells.

? Where is the greatest need for research and development in this sector at the moment?

! One of the greatest needs is the optimisation of technologies that are currently being tested in the field. Those companies who want to launch fuel cells on the market in the short or medium term require efficient support from research institutions. Development goals here are the sturdiness and reliability of the technological systems – in other words, their resistance to loading in everyday operation. A second essential goal is a sufficient lifetime. Thirdly, it is important that these criteria are realised using cost-effective components and systems.

However, there are also key issues in the area of basic research that must be addressed. One of these issues is cost-effective and highly efficient catalysts, above all for oxygen reduction. The other is efficient storage systems for hydrogen.

And yet we shouldn't forget that internal combustion engines have existed for more than 100 years. A lot of money is still being pumped into basic research throughout the world today in order to make these engines even more effective. Fuel cells are only at the beginning of their career in comparison. This means that many years of research will be required to continuously refine these systems and to sustain the competitiveness of our industrial partners.

? Critics are warning us not to enter the "hydrogen world". They argue that the conversion and storage of energy costs a lot of energy itself.

! It's a pity that this discussion is so emotionally loaded. We should look at the issue more dispassionately. Of course, if you can use the electricity generated immediately, there is no point in converting it first. However, we also need to consider other phases. If the sun doesn't shine or the wind doesn't blow, then renewable energies such as solar or wind power won't generate any electricity. This is the reason why there will be more and more fluctuations – at times unpredictable – in the electricity grid in the future. Storage systems will therefore be necessary in any case.

The other topic is that of mobility. Some people ask why we don't simply build battery-powered vehicles. But it's not that simple! If we want battery-powered vehicles to have the same range and take the same amount of time to refuel as other vehicles today, then we would have to wait a very long time for suitable batteries and charging stations to appear on the market. For example, all hopes are pinned on the lithium-ion battery in this field and it is currently controllable in the category up to 50 watt-hours. This is the energy required by a notebook. A car run solely on batteries would require almost one thousand times this in energy storage. It will take a very long time before such batteries are commercially produced reliably and cost-effectively and are readily available on the market. Compared to this, the development of the fuel cell is much more advanced.

In the long term, we will have two energy carriers, both of which will be generated from renewable energies: electric current and hydrogen. Moreover, it is easy to convert each of these energies into the other.

Fuel cells and hydrogen

The global situation regarding energy supply, the environment and the climate demands changes in energy conversion processes and in the choice of energy carriers. Advanced solutions are required: fuel cells and new energy carriers such as hydrogen will have to increasingly contribute to the reliable, efficient and clean conversion of energy, as well as its economic use. In order to successfully develop hydrogen and fuel cell technologies, we must pool the necessary resources. European programmes are already in place today in support of this (Framework Programmes, Joint Technology Initiative), as are a number of German programmes (Energy Research Programme, National Hydrogen and Fuel Cell Technology Innovation Programme) and indeed regional networks for fuel cells and hydrogen. Together, they create the optimum basis for a successful medium-to-long-term solution.

Why do we need new energy carriers?

Advanced energy supply systems are always connected with the issue of handling the available energy carriers correctly. This is why it is important to achieve

- a long-term, reliable, economic and environmentally friendly supply of primary energies,
- the highly efficient production of individual energy carriers from different primary energies,
- an increasing use of renewable primary energies.

Hydrogen will therefore become particularly important as a future energy carrier for the energy economy because it can be used for both conventional and pioneering energy conversion systems – such as fuel cells – and it can be produced from different primary energy carriers. The increased incorporation of renewable energies in the generation of hydrogen necessitates sufficient potential, adequate availability at competitive prices and the creation of new infrastructures.

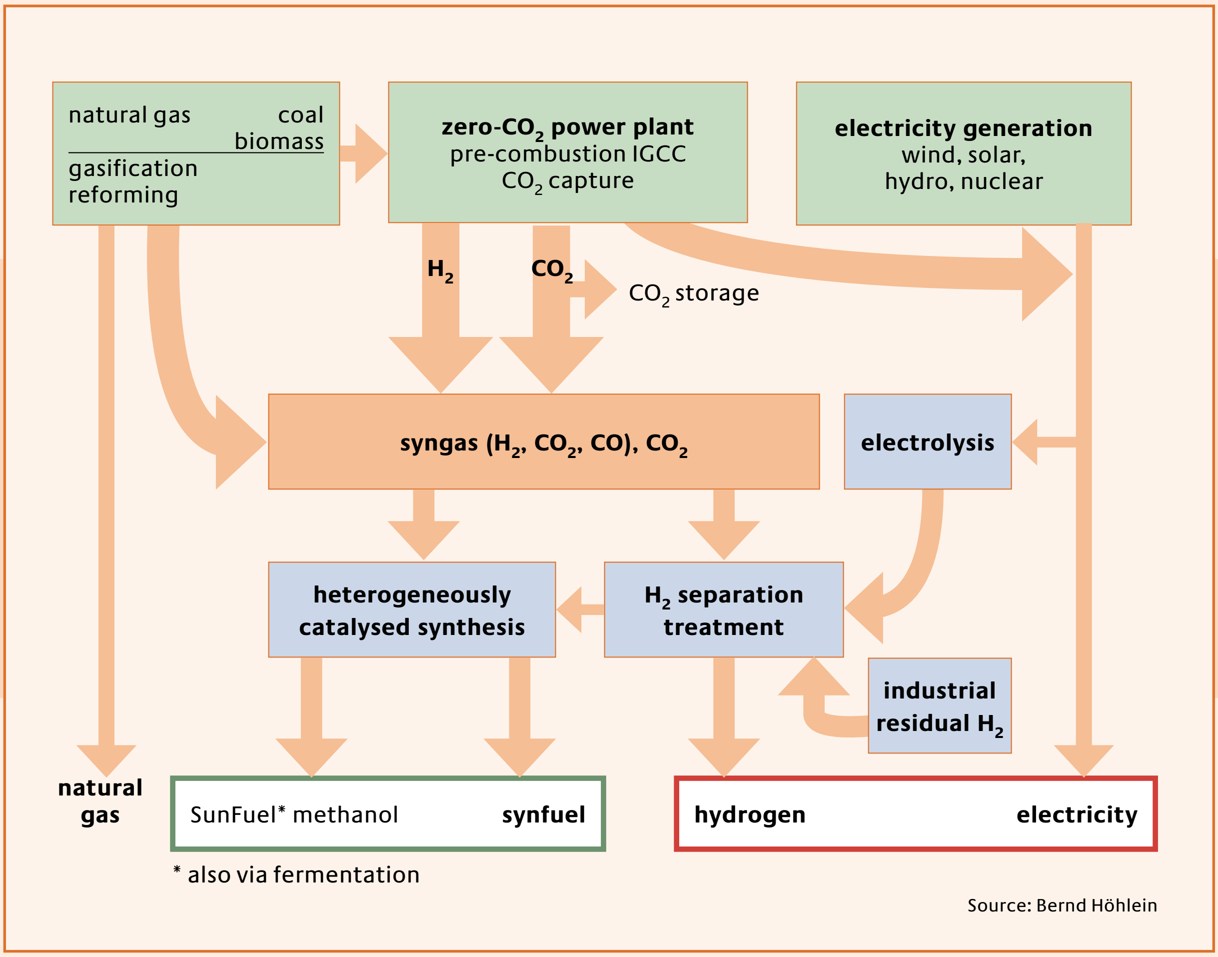
Why do we need hydrogen as an energy carrier?

In the long term, hydrogen and electricity will become a particularly important supply unit. Electric current can be fed directly into the grid and can even be used to transmit information. Due to the fact that it can be stored, hydrogen has an advantage over electricity that makes it particularly attractive for use in mobile applications and to compensate for fluctuations in the generation of power from solar and wind energy. Hydrogen and electricity can be reciprocally converted and they allow for a higher flexibility in the supply system. They are therefore pillars of a future energy economy, which will complement the existing energy economy. Both energy carriers can be produced on a fossil, non-fossil and renewable basis. This opens the way towards zero-carbon generation in the long term.

Hydrogen can be used in a broad spectrum of stationary, mobile and portable applications. Motors and turbines are therefore being developed, as are fuel cells for use as highly efficient electrochemical energy converters. In the field of mobile applications, hydrogen can be used directly as fuel for electric drives in low-temperature fuel cells. Local and global emissions, depending on how the hydrogen is produced, are very low compared to today's conversion systems using conventional energy carriers.

Even today, milestones on the way towards a hydrogen-oriented energy economy can be clearly recognised:

- Early markets for small (portable) applications are being prepared or have already been opened up.
- A vehicle mass market is the target for 2020.
- Initial infrastructures for both applications must be established today by cluster solutions but not yet on a large scale.
- Existing surplus capacities, particularly residual industrial hydrogen, can be used in a timely fashion if treated correctly.
- Mobile filling stations or expanded conventional filling stations are suitable for use in the first supply clusters. The hydrogen will be delivered by trailer, by a pipeline or by filling cartridges at a central facility.



Configuration of an oil-free energy system for the transport sector.

► There is a pressing need for action with regard to establishing logistics for the provision of hydrogen. Challenges include the purity of the gas, pressure adjustment, storage, safety, transport of hydrogen to the customer and structuring the provision of hydrogen at filling stations. Moreover, adequate user acceptance must also be achieved.

New hydrogen generation capacities will only be required for the vehicle mass market from 2020 onwards. However, the course must be set today for a sustainable selection of generation capacities, and work must begin as quickly as possible on meeting the development needs.

To what extent do we need long-term solutions with hydrogen?

A new energy economy with a complementary stabilisation of supply will only come into being gradually in Europe by using different energy carriers. We must begin by using fossil and non-fossil primary energy carriers, and move onto more and more renewable primary energy carriers at a later stage. The use of fossil primary energy carriers increasingly demands carbon capture and storage in geological formations. The extent to which hydrogen is used and generated from renewable sources will increase to the same degree that the currently dominant fossil energy carriers decrease in importance on the market. Efficient and environmentally friendly energy conversion systems, such as fuel cell systems, will thus become more significant. Ultimately, the market introduction of hydrogen, which is competing with other solutions, will also depend on political measures such as environmental legislation and on market introduction programmes, as well as on the development of global energy prices.

Fuel cells: technological diversity – multiple areas of application

In a fuel cell, the energy contained in the fuel is converted into electrical energy. In contrast to engines, the chemical principle of fuel cells is based on “cold” combustion. This allows the high heat losses of the engine to be avoided. The principle was discovered in the first half of the 19th century but it was only after the Second World War that it was exploited in technological developments. Initially, an important area of application was space travel, where this sort of independent system had huge advantages for the generation of electricity (and simultaneously of pure water).

The performance of a fuel cell is determined by two variables: the total capacity and the efficiency. The efficiency refers to the relationship between the energy used in the form of fuels and the energy to be utilised at the end of the fuel cell processes. The electrical efficiency represents the utilisable electrical energy, while the overall efficiency is the total used energy from electricity and heat. As both forms of energy can be used simultaneously in most fuel cell systems, the overall efficiency can be as much as 90 %, as is the case for other combined heat and power (CHP) generation technologies. The electrical efficiency of fuel cells varies between 30 and 55 % depending on the type of fuel cell and its capacity. When high-temperature fuel cells are combined with gas turbines at a later stage of development, electrical efficiencies of up to 70 % could even be reached. The spectrum of achievable power ranges from a few watts, as required for example to supply portable electrical devices with power, to all areas in between up to power plants with a power of a few hundred kilowatts. The target is to achieve a power of a few megawatts.

There are different types of fuel cells and they vary considerably in their design, the materials used and chemical reactions. However, the basic principle remains the same: two electrodes (anode and cathode) are separated by an ion conductor, the electrolyte, which only allows charged particles to pass through it. In this way, two reaction chambers are separated from each other in which different chemical processes occur (oxidation and reduction), which collectively lead to the flow of electric current. An important distinguishing feature among the different types of fuel cell is the electrolyte, which separates the two reaction chambers from each other, but still allows the selective diffusion of specific ions in all cases. In the polymer electrolyte membrane (PEM) fuel cell, a proton-conducting membrane functions as the electrolyte. Depending on the type of fuel cell, the electrolyte can also be liquid potash lye, melted carbonates or solid ceramic materials. The electrolyte

Hydrogen

Hydrogen is the first of the chemical elements listed in the periodic table. It is widespread in a bound state in the form of water and in organic compounds. Hydrogen is technically important for hydrogenation (fat hardening), reduction processes and syntheses (ammoniac, methanol, gas to liquids).

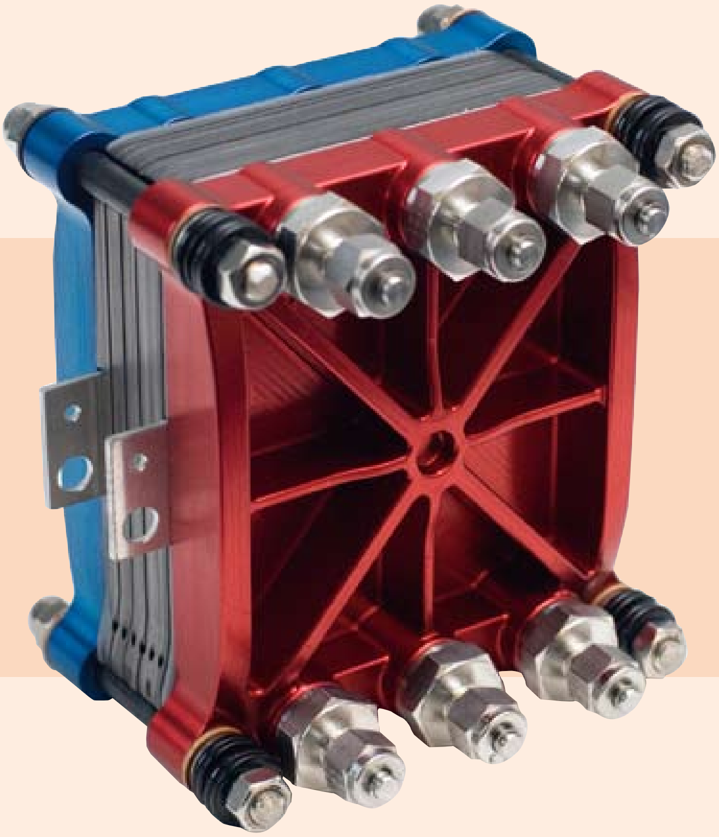
Hydrogen as an energy carrier has been a building block of our technology since it became possible to generate “water gas” (a historical term for a gas mixture with about 50 vol. % hydrogen) from solid fuels. Even in town gas – including gas based on coke-oven gas – hydrogen was used in a gas mixture for lighting and heating purposes. The introduction of natural gas with 80–90 vol. % methane brought an end to the era of hydrogen-rich gas mixtures on the energy market, whereby natural gas reforming and coal gasification have considerable potential for the energy market in terms of generating a hydrogen-rich synthesis gas because they can be used for many synthesis applications up to and including combined power plants with carbon capture and the use of hydrogen.
When energy is applied, hydrogen can be prepared in an isolated form and therefore becomes an energy carrier whose chemically stored energy can then be exploited. The task of generating hydrogen and oxygen from water through the process of electrolysis based on renewable electricity forms the basis today for the global hydrogen technology of tomorrow in combination with fuel cell technology.

Hydrogen energy technology replaces the oxidation of fossil energy carriers with the reaction
$2\,H_2 + O_2 \Rightarrow 2\,H_2O$ (+ 286 kJ/mol for 25 °C and 100 kPa).

When the handling of hydrogen is compared to that of methane or gasoline, the following characteristics become clear:

- high gravimetric heating value at low volumetric heating value
- broad ignition range in air
- high combustion rate in air
- high diffusion rate
- low ignition energy
- low boiling point (–253 °C)
- low-emission combustion (zero-carbon)

Costs and the environmental impacts of this kind of technology depend on the type of primary energy used to generate electricity for the electrolysis – as a substitution for today’s fossil-based commercial processes, such as the reforming of natural gas/water vapour – the energy conversion technologies that are preferred for hydrogen use, the extent to which logistical preconditions must be fulfilled for the provision of hydrogen, and the significance that is attached to the different criteria in the life cycle assessment, and thus the importance ascribed to the internalisation of external costs.



Single fuel cells are packed together to form a stack. The power of the stack is the sum of the single cells.

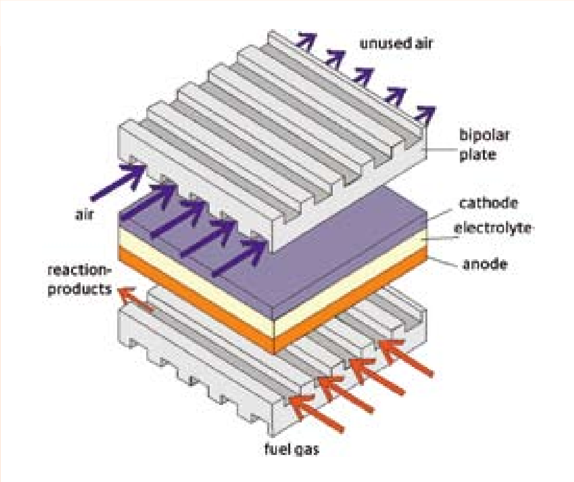
determines both the type of ions exchanged and the operating temperature of the fuel cell. This can range between 60 and 1000 °C.

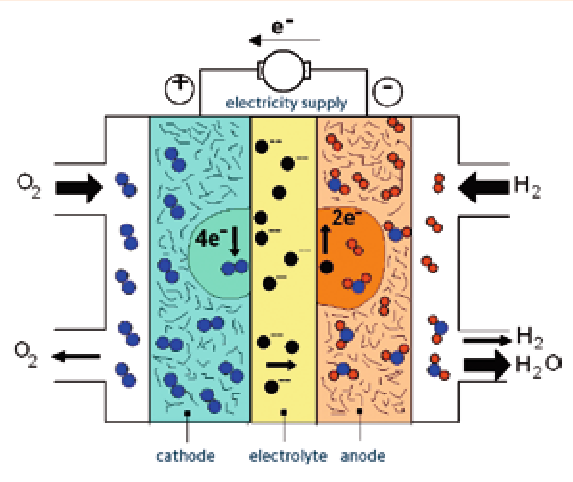
The following explains in detail how a PEM fuel cell is designed. It is surrounded by what are known as bipolar plates. These are composed of graphite, metal or synthetic materials, which are made electroconductive with the aid of carbon nanotubes. These plates have a well-devised system of tiny channels through which the gases flow and are homogeneously distributed on the electrodes. The gases used are hydrogen as a fuel and air as an oxidant. Porous papers made of carbon or graphite fibres function as electrodes. The electrolyte is composed of a polymer membrane with special properties, which allow hydrogen to pass through from one reaction chamber into the other. The membrane is coated on both sides with a catalyst material (such as platinum). Together, the two electrodes and the membrane form what is known as a membrane electrode assembly (MEA), which is contacted to the bipolar plates by means of gas diffusion layers.

As a result of chemical laws, each individual PEM cell – like battery cells – is only capable of providing an electric voltage measuring one volt. For the majority of technical applications, this is not enough. If higher voltages are to be attained, numerous cells must be coupled with each other and electrically connected in series. Combining individual cells in this way creates what is known as a stack.

In the direct methanol fuel cell (DMFC), liquid methanol is used as a fuel which is usually added to water. As is the case for the PEM, a membrane is also used here as an electrolyte. Such methanol-run systems can be optimally used in a power range of between a few watts and a few hundred watts, and are particularly suitable for portable applications. For higher powers, the poor efficiency of this type of cell negatively impacts on the consumption. The biggest advantage of this technology lies in the fact that liquid methanol is much easier to handle and work with as a fuel than hydrogen. There is no need to convert (reform) methanol into hydrogen. A disadvantage of the DMFC, however, is the fact that some of the methanol escapes through the membranes currently available. This means that fuel is lost and the voltage decreases, which in turn causes a poorer system performance.

In what are known as molten carbonate fuel cells (MCFCs), the electrolyte is composed of a melt of lithi-





Design and operating principles of a planar SOFC fuel cell.

um carbonate and calcium carbonate. A mixture of hydrogen and carbon dioxide is used as a fuel at the anode side. This mixture is produced by a reforming process from energy carriers containing methane, such as natural gas, biogas or sewage gas. On the cathode side, a mixture of air and carbon dioxide is used. An MCFC must have an operating temperature of around 650 °C to allow the necessary chemical process to occur. The electrodes are usually made of nickel. Expensive catalyst coatings are not needed because the reactions proceed quickly enough at the operating temperature. Fuel cell systems based on the MCFC are currently capable of achieving a power of around 250 watts. The gross maximum electrical efficiency of a cell is around 55 %. The system as a whole achieves an electrical net efficiency of 46 %.

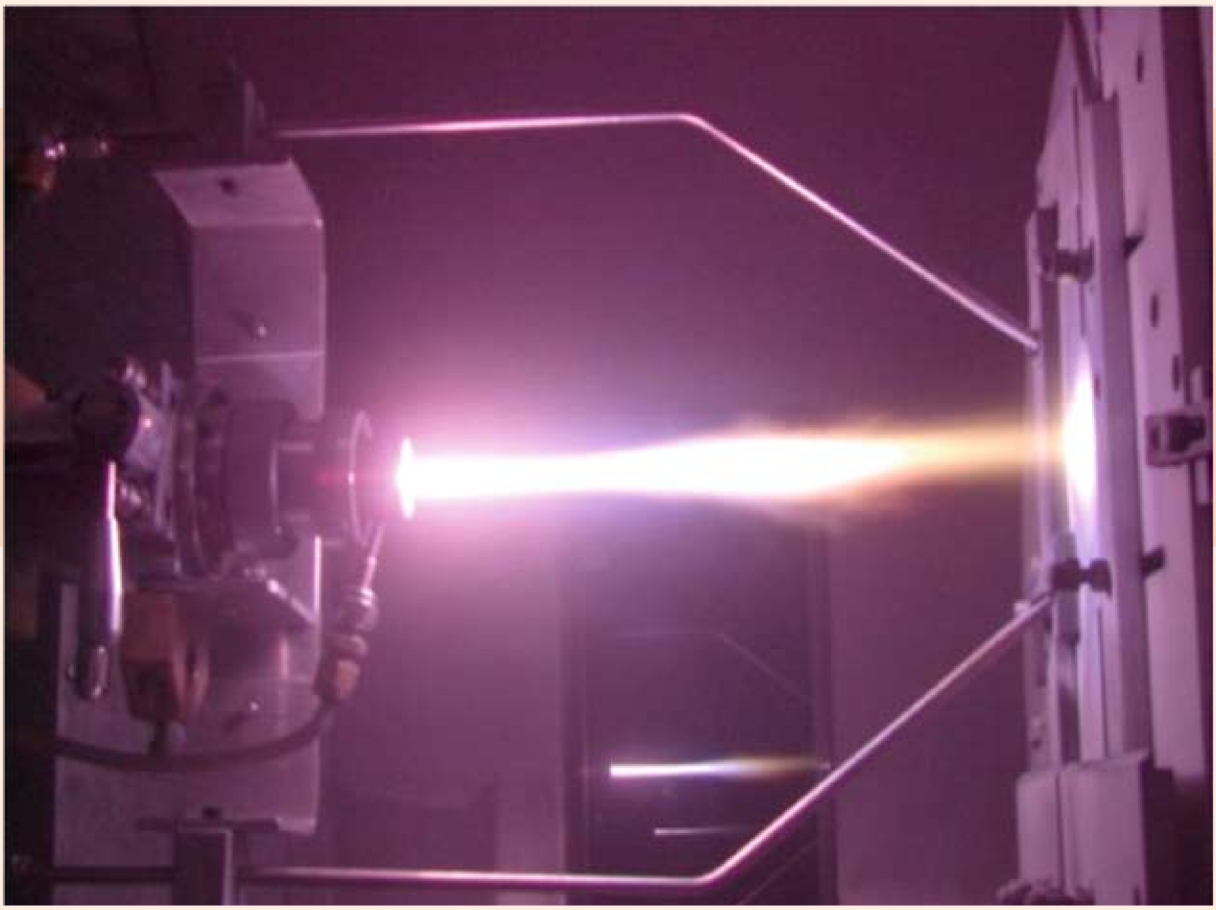
The solid oxide fuel cell (SOFC) has an electrolyte made of a solid oxygen-ion-conducting ceramic material, for example zirconium dioxide (ZrO_2). While the anode is fabricated from a ceramic-metallic material, the cathode is composed of an electroconductive ceramic. The operating temperature of this type of fuel cell is between 700 and 1000 °C. In the SOFC, pure hydrogen is generally used as fuel and atmospheric oxygen is used as the cathode gas (see diagram).

Since fuel cells are operated with pure hydrogen, which is rarely available on site, a reformer must be connected in series. Reforming is a process that converts hydrocarbons (natural gas, biogas, ethanol, methanol, gasoline) into hydrogen. The reforming process is incomplete in most cases. Behind the reformer, the carbon monoxide content can still amount to up to 10 %. In addition, higher hydrocarbons and impurities can be contained in the reforming gas. To minimise the risk of damage to fuel cells, a number of complex purification steps often have to be incorporated in order to extract carbon monoxide, higher hydrocarbons and impurities.

All types of fuel cells are extremely sensitive to impurities. Sulphur fractions in the fuel, for example, attack the electrode and electrolyte material and must therefore be carefully removed.

As a result of their great diversity in terms of power and technology, fuel cells are suitable for use both today and in the future in different areas of application. Over the last few years, BMWi has provided funding for those areas that appear to have the best chances from today's point of view of being quickly transferred and introduced on the respective markets. The following priorities were therefore set:

- use of PEM to supply stationary (houses and buildings) or mobile applications with energy,
- development of applications for what are known as auxiliary power units (APUs) for all sorts of vehicles,
- development of high-temperature fuel cells (MCFC and SOFC) for industrial combined heat and power generation.



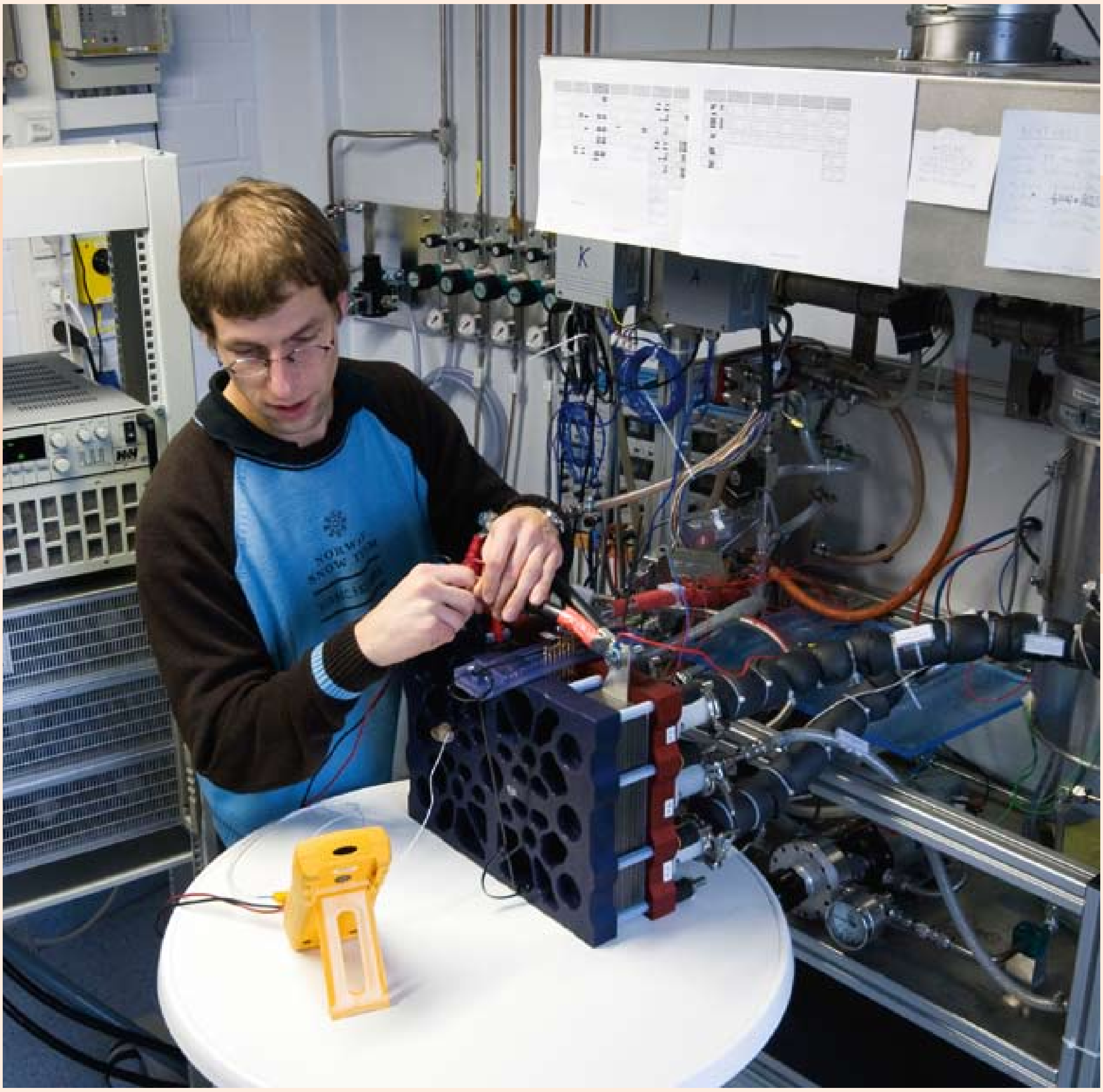
Coating the electrodes of SOFC fuel cells using the plasma spraying process.

Looking over the shoulder of research

At the moment, research is being conducted on a technology known as the high-temperature PEM (HT-PEM). The operating temperature of this fuel cell lies between 100 and 200 °C and is therefore much higher than the operating temperature of "classic" PEM fuel cells. This design also has advantages over both conventional PEMs and high-temperature applications such as the MCFC or SOFC. "This type of system can be operated more dynamically, in other words, it can be brought to its operating temperature quickly and shut back down faster than systems that operate at even higher temperatures," explained Dr. Bernd Emonts from the Institute of Energy Research at Forschungszentrum Jülich. One advantage that the HT-PEM has over the PEM is that it is less sensitive to carbon monoxide (CO) from the reforming process. Conventional PEMs only tolerate carbon monoxide in concentrations of less than 0.005 %. The HT variety in contrast can tolerate 200 times more carbon monoxide, in other words around one percent. Only one single purification step is therefore required after reforming. According to Bernd Emonts, applications for this technology would be in the power range of five to a few hundred kilowatts – electricity that is required for the on-board power supply in aircraft, on boats or in trucks.

The Jülich institute also conducts research on the direct methanol fuel cell (DMFC). In cooperation with different industrial partners, components such as membranes are developed in research and development projects funded by BMWi and practical applications are optimised, for example, the use of the DMFC in forklift trucks .

"As a research institute, we develop basic technologies and demonstrate that they are operational as a system," said Emonts. "The actual application is then developed by the industrial customer," said the researcher explaining how the work is divided between science and industry.



Fuel cell research at ZSW in Ulm.

Optimising the components

The Centre for Solar Energy and Hydrogen Research (ZSW) in Ulm is also working on the optimisation of the classical PEM fuel cell. “Sometimes, people ask us if the fuel cell will ever be ready for the market,” said Professor Werner Tillmetz, a member of the ZSW Board of Directors. “My answer to this is that the PEM works and that there are already commercial products available on the market.” However, there is still a lot of room for improvement: “This type of system must function reliably under all sorts of everyday conditions and it must have an acceptable lifetime,” such are the objectives. A fuel cell in a car should start without any problems, even on a cold winter morning, and it should last at least ten years. According to Tillmetz, other important development goals include a reliable fabrication process and a systematic cost reduction. New materials will play a decisive role here. They should also help to further increase the power achieved per unit area of a cell.

A central point of departure is the electrodes in a cell. In a PEM, both hydrogen (anode) and air (cathode) must be diffused through the material. This is achieved by an elaborate system of fine pores that ensure the equal distribution of gases. The electrodes are each coated with catalytic substances which speed up the desired chemical reactions. At the same time, this type of fuel cell requires sophisticated water management: the incoming air must be humidified, while the water generated must be simultaneously removed

In order to standardise different fuel cell components, extensive development efforts are required.

with the outgoing air. A PEM reacts very sensitively when it runs dry, in other words when it doesn't have enough water. The degradation process is accelerated as a result and the lifetime decreases rapidly. On the other hand, a cell can well and truly "drown" if it has too much water – like what happens in a combustion engine when there is too much fuel.

The bipolar plates are components with a very fine channel structure. The channels, which are either milled or pressed, ensure the best possible distribution of the gases. To improve the geometry of the channels, mathematical procedures from computational fluid dynamics are used. The aim is to distribute both hydrogen and air as evenly as possible on the reaction surfaces of a cell and thus utilise them optimally. At the same time, the flow resistance must be reduced to a minimum. The air on the cathode side has to be pumped into the cell using an air compressor in order to overcome the high resistance. This means a loss in the utilisable power generated by the fuel cell because the air compressor is among the biggest auxiliary consumers of power in such a system.

Catalysts are another key topic of research. In the past, materials such as platinum were applied for this purpose on the cathode side. This metal is comparatively expensive and the prices fluctuate on the world market, often without warning. Under certain conditions, the catalyst material can corrode or exhibit signs of poisoning. The technicians would therefore like to replace platinum completely. Noble metal alloys are the first materials that come to mind – in the long term perhaps even catalysts that are free of noble metals.

Sealing systems pose a challenge for research and development. They are used to keep the electrode chambers and the cooling separate from each other. Inside a stack made of hundreds of single cells, a considerable number of surfaces come together on which different media (hydrogen, air, cooling water) must be sealed against each other. A silicon rubber is generally used for these seals. However, this material is problematic in terms of its durability. For this reason, researchers are currently looking for alternatives, for example in the form of epoxide resins.

In addition to improving the individual components of a PEM fuel cell, other objectives include creating a compact design for individual system components and integrating them into an operational overall system. This includes the intrinsic cell stack as well as all auxiliary devices such as air compressors, valves and heat exchangers. A demonstration device has been developed at ZSW over the last few years. Internally, it is known by the nickname of the "Ulm electricity box". The device is a hybrid of a fuel cell and a suitable battery. It can generate a continuous power of between 500 and 1000 watts, and for a short time, a peak load of three to four kilowatts. The system is fully integrated, which means that the idea of "plug and play" is possible. "Hydrogen goes in upstream, alternating current comes out downstream." ZSW is currently testing the application with a cooperation partner from the yacht construction sector. Supported by BMWi and in cooperation with an industrial partner, a compact 2-kilowatt PEM module is being developed.

On behalf of BMWi, ZSW is also responsible for coordinating a small appliances programme. The aim is to provide assistance for the standardisation of different components. "A key problem associated with the development of fuel cell systems is that there are hardly any fully suitable system components, such as pumps, valves or air compressors, on the market," said Professor Tillmetz. "The components that can be bought from suppliers often don't fit." Small companies often do not have the means to tailor such components to fit their system development. BMWi supports the adaptation development in research and development projects.

Electricity and heat at home

One of the most important future areas of applications for fuel cells is the provision of energy in buildings – so-called domestic energy supply. The reason is simple: fuel cells provide both electricity and heat and are therefore highly suitable as power generators in detached houses or blocks of flats, as well as in small commercial enterprises. In the field of combined heat and power (CHP) generation, fuel cells can play an important role as decentralised energy modules with a customised power supply.

PEM technology is dominant in the area of domestic energy supply. In Germany, a number of companies are currently developing suitable devices within the framework of BMWi-funded projects. These companies include Baxi Innotech and Viessmann. The electric power ranges between 1 kilowatt and 5 kilowatts. The target values for the electrical efficiency of the systems are 30 to 35 %; the overall efficiency (electricity plus heat) should reach almost 90 %. This will allow optimum use of the diminishing supply of fossil energy sources. Such devices have the same dimensions as traditional heaters. For everyday application, they will be connected to the public gas and power supply. Surplus electric power that is not immediately used up in the building itself can be fed into the grid. A downstream conventional boiler for peak loads guarantees adequate heating, even on cold winter days. A suitable storage system would help compensate for fluctuating heating needs during the course of the day. The fact that fuel cells can also be operated very well and with a high efficiency under partial loads – in other words at a lower power than the maximum – makes their application in domestic energy supply beneficial because power and heating needs tend to fluctuate over the course of the day.

Research and development work in this sector is currently being conducted on all components of a domestic energy system that is suitable for daily use. This begins with the reforming of fuels such as natural

A fuel cell assembly for the generation of energy (electricity and heat) in buildings.

gas and goes beyond purification technology, ranging up to control systems and current transformation (from direct current to alternating current).

Within the framework of a project that began in 2000, which is funded by BMWi, Viessmann is working together with partners from science and industry to develop a power generator for detached houses based on the PEM. This generator will provide an electric power of two kilowatts. Its thermal power (waste heat released from the fuel cells and from gas treatment) is 3.5 kilowatts. The electrical efficiency will be more than 30 % and the overall efficiency almost 90 %. In 2006, the first test facilities went into operation and field tests will follow shortly. The company is aiming for market introduction in 2010.

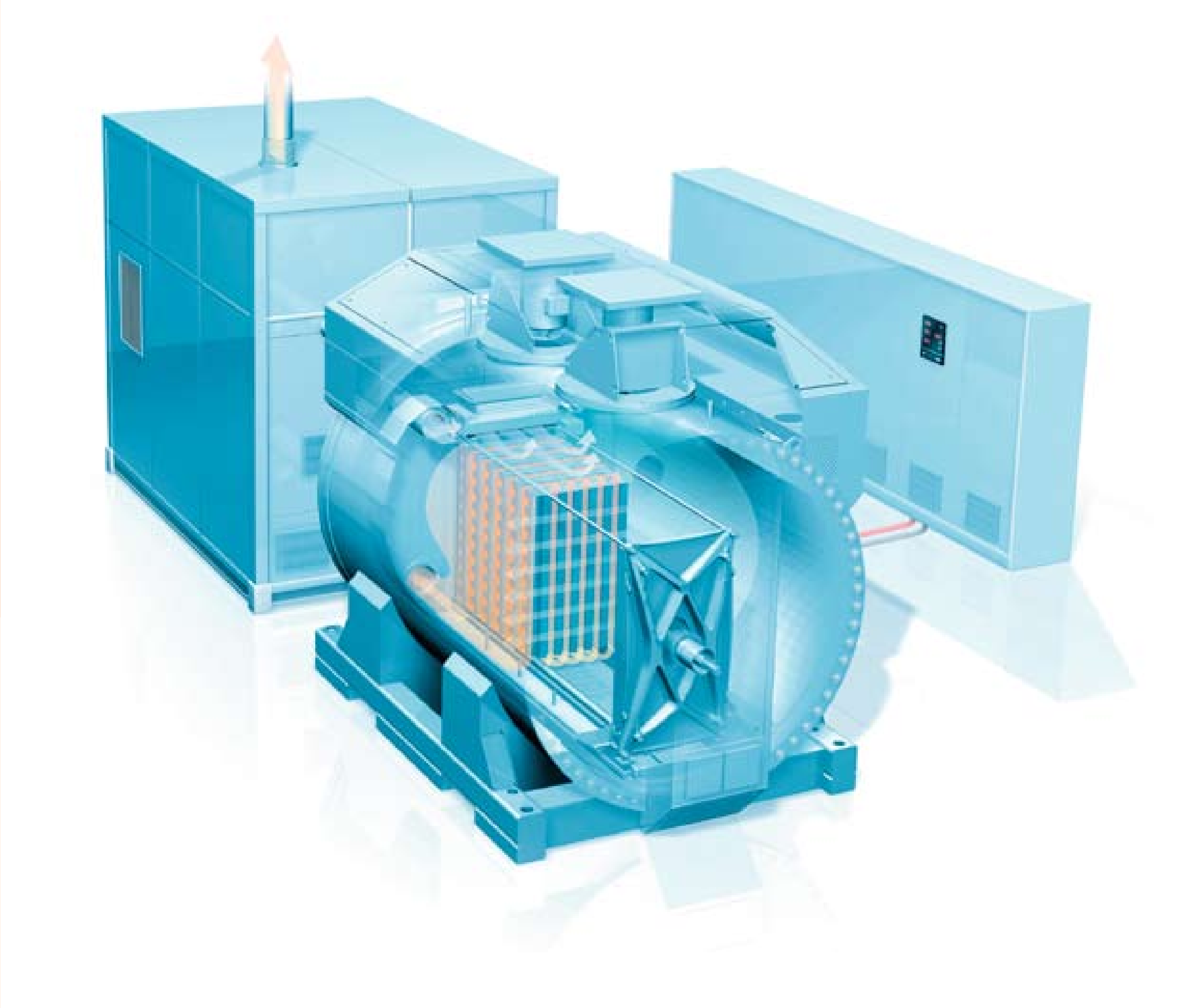
Work has also begun on applications of SOFC technology in the domestic energy supply sector. For example, the Vaillant company is currently cooperating with Webasto, a supplier to the automotive industry. Webasto has been working on fuel cell systems that generate electric power on board vehicles from gasoline or diesel for a number of years. The aim now is to adapt such modules for operation with natural gas and to put them into operation in smaller fuel cell heating devices. The project is funded by BMWi.

The fuel cell as a power plant

What do the waste water plant in Stuttgart, University Hospital Magdeburg, the sewage treatment plant in Moosburg in Bavaria and the Munich data centre of DeTelmmobilien GmbH have in common? The answer is fuel cells. To be more exact, a certain type of fuel cell technology can be found in these establishments – the molten carbonate fuel cell (MCFC). This energy converter generates both electricity and heat, which can be used for a variety of purposes. The corresponding power plants are produced by the company MTU ONSITE ENERGY in the Munich district of Ottobrunn. Many of these prototype facilities were built and put into operation with the aid of grants from the Federal Government's Future Investment Programme (ZIP)

When you walk into the production halls of MTU ONSITE ENERGY, the first things you notice are the silver metallic steel boilers with a diameter of almost three metres. In these steel boilers are the main fuel cell modules. Each boiler contains a stack of a total of 350 MCFC cells. They also contain a mixing chamber for the different gases that are pumped in and out, a circulating air compressor, and a heating system that heats the entire device to its operating temperature of 650 °C. "This heating process must be particularly gentle in order to avoid heat stresses in the components," explained Dr. Manfred Bischoff, Technology Manager at MTU ONSITE ENERGY. The process can therefore take a number of days under test conditions. The cell module is supplemented by a separate gas processing system, which desulphurises, heats and humidifies the fuel. Last but not least, an insignificant looking switch box contains the system controls. This is where the direct current that comes from the fuel cells is transformed into grid-compatible alternating current.

"The fuel cell module and the ancillary components are like an engine and a vehicle," according to Bischoff. This type of "hot module" has an electric power of 250 kilowatts and does not just generate power but also 180 kilowatts of heat with a temperature of up to 400 °C. This is used, for example, by industrial clients as process heat in the production process. In the Munich telecommunications company, DeTelmmobilien, in contrast, the heat is converted into cold and is then used for air conditioning. "When



Configuration of an MCFC "hot module" fuel cell system.

you use the power and heat generated by this type of fuel cell, then you can achieve an overall efficiency of more than 80 %," said Manfred Bischoff.

This type of system can be fed with conventional natural gas as well as with gases that occur in biomass facilities and sewage treatment plants or in landfill sites. "These gases contain around 40 to 50 % methane. The rest is made up of nitrogen dioxide and carbon dioxide," explained Bischoff. "However, MCFC technology can convert what are known as low-energy gases into electricity in a highly efficient manner." One of the main advantages of MCFC technology is that once sulphur and higher hydrocarbons have been separated from the fuel, it can be converted internally into hydrogen. This has an effect on the structure of the system. The reformer is not located – as is the case in PEMs – in front of the actual fuel cells but rather in the same casing as the fuel cell stack. Due to its high efficiency, with the same amount of fuel an MCFC can generate 30 % more electrical energy than a conventional power plant of the same power or than a combustion engine.

MTU ONSITE ENERGY has already built 20 of these facilities and they are up and running at different sites. They are all test facilities, the construction and installation of which was only made possible through public funding. In University Hospital Magdeburg, one of these hot modules has already been in operation for 30,000 hours. "Our target lies around 40,000 hours," said Bischoff. "We are close to proving that these power plants have a competitive lifetime." However, "the biggest stumbling block is still cost," explained the manager. Above all, the materials required cannot yet be bought in large enough quantities. Furthermore, these plants still have in-built safety elements that make them more expensive than they need be. "We are now implementing value engineering," emphasised Bishoff, "to allow us to drive costs closer to the market prices."

In the “hot module”, the design engineers have succeeded in incorporating all hot components in the one common casing. This does not just make some of the peripheral devices redundant but it also allows the efficiency to reach new levels. Without a flame and without moving masses such as rotating turbine blades or a piston stroke, the hot module directly converts the energy of the gas into electricity and heat.

While for a long time MTU ONSITE ENERGY used to buy the actual fuel cells from their American partner FCE, the company actively entered cell development and fabrication a few years ago. Under the keyword “euro cell” and with funding from BMWi, this in-house development is now on the threshold of market introduction: one of the first plants with this core has been delivered to a customer and now has 6,000 hours of operation behind it in the test phase.

For the euro cells, new cheaper materials are being used and the fabrication processes has been changed. This allowed the process temperatures to be successfully decreased, which means that cells can be fabricated in a more environmentally friendly and also cheaper manner. At the same time, the aim is to generate more power with a cell stack. For example, new semi-finished metal products are now being used. They are particularly beneficial in the core of the cells for instance for current collectors. Such materials are incidentally also used in battery production.

The trend for the future is clearly going in the direction of bigger, more powerful devices according to Bischoff: “Customers want power plants with a power in the megawatt range.” While fuel cell stacks contain a maximum of 350 cells at the moment, the aim is to extend this step by step to create stacks with 600 cells. This type of stack would deliver a power of around half a megawatt. “The system would then be such that we could integrate two of these stacks to form one power plant.”

The number of cells inside a stack, in contrast, cannot be increased at will. “Thermomechanical effects increasingly occur because the materials expand to a different degree when being heated to the operating temperature of 650 °C,” explained Bischoff. Such effects become more pronounced the more cells that are stacked on top of each other. In addition, they are difficult to calculate in advance, which means that extensive tests are necessary in each case.

Molten carbonate fuel cells such as the hot module generate both electricity and heat.

Another area of application for MCFC devices in the future is seen by Bischoff in horticulture, where in addition to electricity and heat, the carbon dioxide (generated when the natural gas is reformed) can be put to use in greenhouses to promote growth.

Portable and mobile applications

Fuel cell development is most advanced today in the area of portable applications. The first products are already available on the market, and according to estimates by experts, fuel cells will achieve an appreciable share of the market in the foreseeable future as replacements for batteries. In the low-power area (a few hundred watts), the DMFC appears to be doing well. Possible applications here range from powering portable electronic devices (for example, laptops) and small vehicles (scooters, forklift trucks) to the on-board power supply in vehicles. The company Smart-FuelCell (SFC) is currently the market leader in this field. SFC succeeded in significantly reducing the specific costs of the fuel cell and increasing the specific energy density within the framework of a BMWi research and development project. The result: smaller and cheaper devices. The products manufactured by SFC can be used in caravans, leisure boats or scooters, as well as in weather stations.

A tank cartridge with ten litres of methanol would cover the energy demand of a caravan for around two weeks. The liquefied petroleum gas propane, on the other hand, is used to operate a fuel cell currently being developed by the Munich-based company Truma, small series of which have been produced since 2008. The device has a maximum power of 250 watts and is also suitable for use in caravans and mobile homes.

The field that has driven fuel cell technology particularly strongly for a number of years is the automobile industry. Two thirds of all fuel cell applications will occur in this field, according to appraisals by experts. Numerous car manufacturers have been developing and testing drive systems for cars based on fuel cells for a number of years. In Germany, Daimler, Volkswagen, Opel and Ford are particularly active in this area. Test vehicles have already covered millions of kilometres. The first commercial vehicles for private customers are already available – albeit not yet at competitive prices. Experts expect that commercial cars with a fuel cell as their main drive will be launched on the market for the first time at the end of the next decade. Up to now, research and development in this sector has been predominantly driven by the car manufacturers themselves with no public funding.

Over the last few years, developers have improved the cold start performance of fuel cells, for example, and showcased the first systems that can also be started at minus temperatures. Other improvements are related to the power density, allowing fuel cells to provide significantly more power per volume unit than before.

Fuel cells are suitable for use not just in cars but also in larger vehicles. For example, in September 2006, the small resort of Barth on Germany's Baltic coast received a fuel cell bus. The project, which was funded in its starting phase through the Federal Government's Future Investment Programme (Zukunftsinvestitionsprogramm; ZIP), has Barth's waste water treatment plant to thank: its capacity is too small to deal with all of the tourists that come to the town during the summer months. The solution: extra oxygen is pumped into the activated-sludge tank in order to increase the efficiency of the facility. The cheapest way to generate pure oxygen is through electrolysis by splitting water. This process also produces hydrogen. This hydrogen from the waste water treatment plant can then be used for the bus.

A petrol and diesel fuel cell (SOFC) for the generation of electricity for the on-board electrical system in a car.

The bus is a hybrid vehicle. In addition to the fuel cell system, it has a battery for recovering the braking energy. The fuel is stored in the form of gas in two 320-litre tanks at a pressure of 200 bar. The vehicle's top speed is 70 kilometres per hour and it has a range of 180 kilometres. It can transport a total of 22 passengers. Other buses with a fuel cell drive are in operation in other cities such as Hamburg. They are being run as part of an EU project entitled Clean Urban Transport for Europe (CUTE). In the project, a total of 27 buses powered by fuel cells are being tested in nine European cities. The fuel cell buses based on the Citaro were developed by Daimler. BMWi is also involved in the project through the co-financing of two hydrogen filling stations.

In the Clean Energy Partnership (CEP) project in Berlin, leading technology, mineral oil and energy companies, together with the majority of German car manufacturers, operate a fleet of cars with hydrogen drives and they also run a hydrogen filling station. The majority of the cars have a fuel cell drive, but some also demonstrate that an internal combustion engine can be run on hydrogen. In the second phase,

In many places in Germany, buses with fuel cell drives are already a reality.

the number of vehicles being tested in the project will be significantly increased.

Experts expect to see auxiliary power units (APUs) run on fuel cells from 2012 onwards. APUs are not intended for drives in cars, trucks or buses, but rather for ancillary components, which intensively consume energy, such as air conditioning, seat heating and parking heaters. This pushes the classical system composed of a battery and generator to the limits. Fuel cells would basically replace the generator.

Development projects focusing on using the SOFC technology in APUs are currently underway at the Jülich Institute of Energy Research (IEF). The project known as ZeuS is headed by an industrial consortium and is financially supported by BMWi. “Applying this technology in cars is an enormous challenge,” said Dr. Robert Steinberger-Wilckens, head of the fuel cell project at IEF.

A number of questions must be answered. How do fuel cells react to continuous vibrations in the driving mode? How fast can they start? What lead-up time do they require before they can deliver maximum power? “Our aim is to bring all of the components together in an integrated and compact device, which is robust against all possible external influences,” explained Steinberger-Wilckens. “A car often drives over potholes or generates vibrations: we must ensure that this does not damage the fuel cell.”

One of the objectives of the ZeuS project is to design a lightweight stack construction for mobile applications. Chromium stainless steel is used as the material for the bipolar plates. The single cells are surrounded by suitable connecting devices (interconnects) and are then joined together to form a stack. The interconnects are made of metal and designed so that both fuels and gases can be fed in and extracted. All internal seals are made of glass or glass ceramics. In the industrial collaborative research project ENSA running in parallel, a suitable peripheral device is being developed for the SOFC stack. A complete APU system will go into production in a few years. It will be

Taking a peep under the bonnet of a fuel cell car and servicing it on the lifting platform.

suitable for use in cars, trucks and buses. This new technology will open up excellent market opportunities for the automobile accessory industry, which has dedicated itself to this development.

The National Hydrogen and Fuel Cell Technology Innovation Programme

The German Federal Government has supported hydrogen and fuel cell technologies up to now mainly by funding research and development projects. Now, the government is going a step further: the Federal Ministry of Transport, Building and Urban Affairs (BMVBS), the Federal Ministry of Education and Research (BMBF), and that of Economics and Technology (BMWi) have jointly drafted the National Hydrogen and Fuel Cell Technology Innovation Programme. In addition to research grants from BMWi for applied research and technological development, BMVBS will make around € 500 million available over the next ten years for demonstrations and market preparation in the area of transport, domestic energy supply and industry, as well as for portable applications. The demonstration measures will be achieved in general in the form of lighthouse projects, which will be used to significantly increase the public perception of hydrogen and fuel cell technologies. BMVBS has set up NOW GmbH as a national organisation for hydrogen and fuel cell technologies. NOW will be responsible for putting the planned demonstration measures into practice as appropriate. Furthermore, NOW will be responsible for the general coordination of the programmes set up by the federal states on the one hand, and of the European and international initiatives on the other. Above and beyond this, NOW will ensure that the results of the demonstration measures flow back into the research and development activities of BMWi.

Outlook

With its wide range of applications, fuel cell technology has the potential to supplement and even supplant the established technologies of today. The advantages of fuel cells, particularly their high efficiency (even under partial loading conditions and in small devices), however, are still counteracted by high fabrication costs and the not yet competitive lifetime of the various fuel cell systems. “A problem associated with fuel cells is that they are cutthroat competition for many applications with conventional, classic energy conversion systems, such as the internal combustion engine or the battery,” said Professor Werner Tillmetz. “This technology must be able to hold its own, particularly in terms of costs, robustness and lifetime. At the moment, this is not always possible.”

Fossil-fired power plants are a topic of critical public discussion at the moment. But we need them. And new technologies are making them more and more efficient and environmentally friendly. An interview with Prof. Dr. Alfons Kather, head of the Institute of Energy Systems at Hamburg University of Technology (TUHH) and spokesman of the advisory board of COORETEC, an initiative set up by BMWi for carbon reduction technologies.

"Carbon dioxide must be captured and stored"

? Fossil energy carriers are limited and must therefore be used as efficiently as possible. How can power plant engineering help us here?

! The decisive factor is increasing efficiency. The more effectively every tonne of fuel – whether it's natural gas, lignite or hard coal – is used to generate energy in every power plant, the more economically we use our limited resources. At the same time, this also means that less carbon dioxide is released into the environment per generated unit of energy.

Furthermore, I believe that the combined heat and power generation should be promoted. This would mean that in addition to the electricity generated, the heat that is usually discharged into the surrounding area via the condenser and cooling tower must also be used. This would make a much higher utilisation rate possible and allow us to get the most out of the fuel.

This increasing of the electrical efficiency in conventional power plants is even more important because the technical methods that we are currently working flat out to develop in order to capture the carbon dioxide produced by power plant processes, store it geologically and thus remove it permanently from the environment lead to large efficiency losses. This type of modern power plant with integrated carbon capture is, in my opinion, the power plant of the future.

? Why is this carbon capture so important?

! Although the CO_2 emissions can be reduced substantially by replacing old coal-fired power plants with new state-of-the-art power plants, we will only be able to meet the national, European and even international targets for CO_2 reduction if CO_2 above and beyond this is captured.

? Carbon capture itself requires energy. Does the separation process make economic or ecological sense?

! Carbon capture makes sense if we are sure that CO_2 is the major cause of climate change. Then, there is no question as to the ecological benefit. However, it does currently cost us around 10 % of the efficiency. We are in the process of lowering this value. Roughly, carbon capture means around 20 % more fossil energy carriers are consumed. And of course, the investment costs for power plants are also higher. In other words, it costs us money. This will lead to an estimated increase of 15 to 20 % in the price of electricity for private consumers, and relatively seen, even higher prices for industrial users. Whether this is economically viable will depend on the "price of CO_2" – in other words, on how high the penalty will be if a certain amount of CO_2 is produced and released into the atmosphere.

? Can we store the huge amounts of carbon dioxide that would then be produced on a long-term basis in an environmentally friendly manner?

! That is a question for geologists! I am convinced that in the long term, this will cause neither health problems for humans nor environmental problems. Storing CO_2 is no more dangerous than storing natural gas as is common practice today. An economic risk exists at most in the fact that the storage formations into which we pump the CO_2 may have to be abandoned earlier than planned and new storage formations may have to be developed at high costs instead.

At the moment, there is not enough application-oriented research being conducted on what actually happens geologically and chemically during the transport and storage of carbon dioxide in potential storage formations. This research requires larger quantities of carbon dioxide. We must therefore build a plant as fast as possible to produce this. Then, we would be able to investigate storage much more intensively.

? Do you see any problems in terms of the social acceptance of fossil-fired power plants either with or without carbon capture and storage?

! Yes I do, particularly in the negative emotional attitude towards coal which has developed recently. Open and transparent public relations are required to help the general public realise that a reliable power supply is impossible without coal, and to use this as an argument to improve the acceptance of both hard coal and lignite.

Modern power plant technologies

Right beside the lignite power plant in the industrial area known as “Schwarze Pumpe” in Eastern Germany, the first pilot plant for the oxyfuel process is up and running. The pilot power plant emits 90 % less CO_2 than conventional power plants.

Compared to the lignite power plant right next door with its huge boiler house and two large cooling towers, the new pilot power plant is much more modest. And yet it is here in the district of Spremberg in Brandenburg in the industrial area known as “Schwarze Pumpe” that the power plant technology of the future is being developed. In Lusatia between Cottbus and Dresden, the first pilot power plant in the world that emits 90 % less carbon dioxide than conventional power plants went into operation in September 2008. The lignite-fired power plant from the engineering company Vattenfall is based on the oxyfuel process. This process concentrates the purity of carbon dioxide to between 98 and 99 %, which subsequently allows it to be liquefied, compressed and stored permanently in an underground geological formation. With 30 megawatts, the thermal load of this pilot power plant is still modest. For the time being, only steam will be generated here. In 2012, the results of the test phase will be incorporated into a demonstration power plant, which will be capable of achieving 25 times the thermal power and will be used to generate electricity. By 2015 at the latest, experts expect it to be clear whether this process is reliable and economic and whether it can be applied on a large industrial scale.

Pilot plants like that in “Schwarze Pumpe” are being constructed at a number of sites in Germany, and also in Europe and other industrial nations. They may be based on different processes but they all have the one objective: to run power plants based on fossil fuels (coal or natural gas) without causing major pollution. This applies to the climate-damaging greenhouse gas of carbon dioxide in particular.

40 % of the global anthropogenic CO_2 emissions originate in power plants fired by fossil energy carriers. For its part, coal (lignite and hard coal) accounts for 80 % of these emissions. The steadily increasing energy demand, particularly in what are referred to as the catching-up countries such as China, India or Brazil, will also see the CO_2 emissions increase even more over the next few years. Despite this, fossil energy carriers will continue to play a key role throughout the world. The International Energy Agency (IEA), for example, predicts that even if renewable energies are considerably expanded and energy efficiency is

increased significantly, fossil energy carriers will still have to cover around 70 % of the global energy requirements in 2050.

The increase in the concentration of carbon dioxide in our atmosphere, however, is the main cause of global climate change according to the Intergovernmental Panel on Climate Change (IPCC). At the same time, it has become apparent throughout the world that fossil fuels are only available in limited quantities, and as a result, they are becoming more and more precious and expensive. Using these energy sources sparingly while simultaneously reducing greenhouse gas emissions has therefore become an important ecological and economic objective.

In Germany, research in this field has been focused for a number of years in the research and development initiative known as COORETEC (carbon reduction technologies), which is supported and funded by BMWi. The energy industry, plant engineers and researchers jointly developed the COORETEC lighthouse project. This project shows how fossil-fired power plants can be adapted for the future. The central objectives here are environmental compatibility, economic viability and security of supply.

“Research and development activities in COORETEC are organised according to the different technological processes that play a role here,” explained Prof. Alfons Kather, who lectures at Hamburg University of Technology (TUHH) and is the current spokesman of the COORETEC advisory board. “What is new in this programme is that entire processes are being investigated instead of individual components, as was the case in the past.” The advisory board is made up of five working groups. These groups are concerned with gas-fired combined cycle power plants (GCC), coal-fired steam power plants with different options for downstream carbon capture (integrated gasification combined cycle; IGCC), the oxyfuel process (combustion in an oxygen atmosphere), as well as the geochemical and technological principles of carbon transport and storage. The GEOTECHNOLOGY programme also integrates BMBF funding measures for carbon storage into the advisory board.

The process-oriented structure of the programme has the advantage that research can be tailored to the specific requirements for each technology and selectively improved. “We take a look inside all of the processes in order to detect weak links in the process chain and eliminate them,” said Kather. Each of the working groups is made up of representatives from both research institutions and industry.

The five working groups are further supported by the turbomachines working group, which is concerned with the further development and optimisation of turbines and compressors for the various power plant processes. Further information on COORETEC can be found at www.cooretec.de.

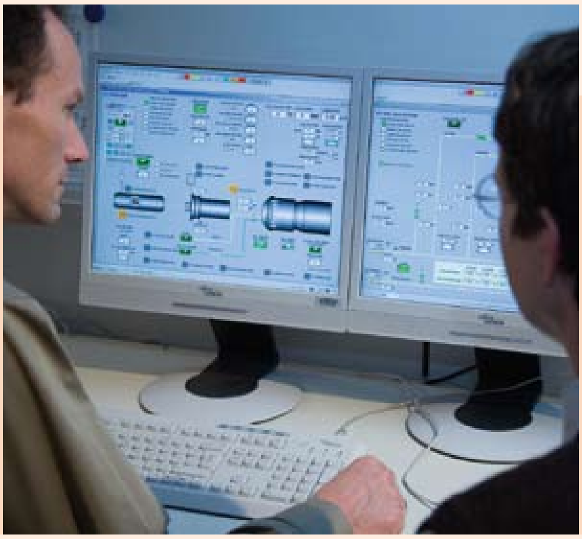
Reducing the level of carbon dioxide emitted by power plants can be achieved in two ways. One of these involves increasing the efficiency of the power plant. This allows us to use available fuel more effectively, and at the same time, it ensures that less CO_2 is discharged into the atmosphere per kilowatt hour of generated electricity. The second solution involves capturing the carbon dioxide produced inside the power plant itself – either before or after the actual combustion process (pre- or post-combustion capture). There are currently three different technologies that can be used for this purpose. Post-combustion capture and the oxyfuel process are based on the steam power plant process, while the pre-combustion process is based on the IGCC process.

Once it has been captured, the CO_2 must be compressed, transported to suitable underground geological formations or reservoirs and stored safely. Former natural gas or oil reservoirs can be used for this purpose, as can deep saline aquifers. Such capture and storage procedures are referred to under the name of “carbon capture and storage” (CCS).

The long-term technological aims of the COORETEC lighthouse project are:

- to increase the efficiency of the basic processes in steam power plants and IGCC to more than 50 %,
- to significantly decrease the costs of carbon capture and storage,

The largest gas turbine in the world at present, SGT5-8000H, was manufactured by Siemens in Berlin.



On 20.12.2007, the SGT5-8000H was fired up in the Irsching power plant near Ingolstadt. The German Economy Minister Michael Glos attended the event.

- to lower the efficiency losses caused by the processes required for this from today's (estimated) 12 – 13 % to significantly less than 10 %, and

- to design all technological systems so that they are both reliable and flexible, and are therefore capable of reacting quickly and effectively to the permanently changing conditions on the international electricity and energy markets.

Combined cycle gas and steam power plants

In a gas turbine, the hot waste gases from a combustion process are used to drive a turbine – and via a connected generator – to produce electricity. First, a compressor sucks air in and feeds it into the combustion chamber. Here, the compressed air is burnt together with the fuel (natural gas or light heating oil). This produces a waste gas with a temperature of about 1350 °C and a pressure of up to 35 bar, which flows into the turbine. In the turbine, its pressure and temperature decrease. The experts say that "it relaxes", and transfers its energy to the turbine blades, which causes the turbine shaft to rotate and drive the generator via an electric coupler.

When the gas reaches the first row of blades, it has an initial temperature of around 1350 °C. When it leaves the turbine, it has been cooled down to around 600 °C. The efficiency of a gas turbine improves the higher the initial temperature at optimal pressure. However, temperature and pressure cannot be increased at will but rather only to a level that does not damage the material of the turbine components. Technological progress in coating and cooling these components has already led to huge increases in gas temperature over the course of the last few decades. The most efficient gas turbine in the world at the moment is capable of achieving an electrical power of 340 megawatts. It is currently being tested in the E.ON Irsching power plant by the manufacturing company, Siemens Power Generation. BMWi supports the scientific work associated with these tests in the form of funding.

Pure gas turbine power plants can achieve an efficiency of almost 40 % today. This value – and with it the energy yield – can be hugely improved if the gas turbine process is coupled with a steam turbine process. The waste gas from the gas turbine, which still has a temperature of hundreds of degrees, can then be used to generate steam, which in turn drives downstream steam turbines. This is known as a combined cycle gas and steam power plant. Such a power plant is already capable of achieving an efficiency of almost 60 %.

The main aim of research work here is the same as that on all other power plant technologies: to increase the efficiency even more. Every increase means better fuel utilisation, which simultaneously leads to reduced carbon dioxide emissions in relation to the

The SGT5-8000H provides a power of 340 megawatts in the Irsching power plant. After the test phase, this facility will be expanded to a highly efficient combined cycle power plant with a power of around 530 megawatts and an efficiency of more than 60 %.

power generated. Engineers are aiming to make an efficiency of 63 % a reality for combined cycle power plants by the year 2020. In order to achieve this, the temperature of the gases that drive the turbines must be increased to more than 1500 °C and the effectiveness, in other words the internal efficiency of the compressor and turbine, must be boosted.

The materials and components used today in turbomachines are not designed to withstand the envisaged temperatures. This is the starting point for research. Resistant protective coatings must therefore be developed to protect the combustion chamber and turbine blades from the hot waste gases. Ceramic materials such as zirconium oxide are used today, but there is room for improvement here. Novel materials are therefore being tested in parallel, whereby many layers made of different materials are possible in some cases. Similar protective effects can also be achieved by an even more efficient cooling of the components. All components of the elaborate and complicated cooling system, in particular the interior of the blades, are therefore being examined very closely. Efficiency losses also occur as a result of leakages, which is why the various different sealing systems (mechanical sealing or air seals) are taken as a starting point by researchers for such turbomachines.

At the same time, work is underway on optimising the aerodynamics in the compressor and turbine in an effort to increase the internal efficiency of the components. Another prerequisite for success is to coordinate the gas and steam turbine processes in a combined cycle power plant better with each other. One way of doing this, for example, is to adapt the outlet temperature of the gas from the gas turbine to optimally suit the temperature of the steam process.

There are innumerable “adjusting screws” in a plant as complex as this, which engineers can “tweak” to progressively optimise the processes. However, these processes tend to have such a strong influence on each other that tweaking one screw automatically has an impact on lots of others. For example, one of the most highly stressed components in a gas turbine is the trailing edge of the turbine blades. For aerodynamic reasons (prevention of flow eddies), these should be as narrow as possible. However, this is also where the thermal and mechanical stresses on the material are greatest. At the same time, the cost of fabricating these components must also be kept within reasonable limits. Compromises must therefore be found that allow the conflict between structural stability, thermal stability, flow behaviour and manufacturing costs to be resolved in the best possible way.

Steam turbine in the Mainz-Wiesbaden combined cycle power plant. With an efficiency of 58 %, it is one of the most efficient in the world.

The most economical method for capturing carbon dioxide in combined cycle power plants is by means of the post-combustion capture process. This involves piping the waste gases from the gas turbine into a “scrubbing system” where the greenhouse gas is removed with the aid of chemical processes (see p. 68 “Scrubbing carbon dioxide”).

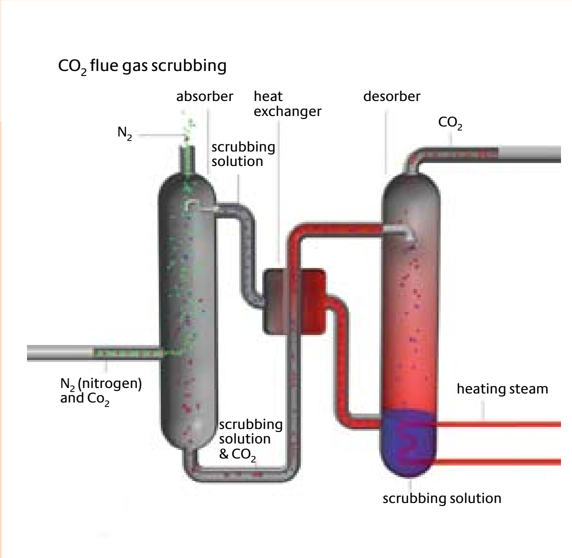
Coal-fired steam power plants

In steam power plants, fuels such as lignite or hard coal are burnt in steam generators (boilers) to generate steam under high pressure. This steam is then piped into a turbine, which rotates when the steam relaxes and drives an electricity generator to which it is connected by an electric coupler. As the steam flows through the turbine, it cools down and begins to condense into drops of water. The turbine is connected to a condenser, in which the steam is fully condensed to water once again. A steam turbine has a high-pressure, a medium-pressure, and a low-pressure section. The blades in each of the sectors are designed differently in order to make optimum use of the different pressure conditions. The longest blades can be found in the low-pressure area: in modern power plants, they can be up to two metres long.

The most modern generation process in a lignite power plant has an efficiency of 43 %, while hard-coal power plants achieve around 46 %. On average, all (old and new) power plants in Germany currently have an efficiency of 38 %; worldwide this figure is only 30 %. “If we were to replace all hard-coal-fired steam power plants in the world with state-of-the-art plants,” said Professor Alfons Kather, “we would see a decrease of around 35 % in the carbon dioxide emissions from these power plants”.

The best performances achieved to date were made possible by improving all of the components in a steam power plant. Most importantly, this includes what are known as the steam parameters: the maximum values for the pressure and temperature of the steam fed into the turbine. To summarise, the hotter the steam, the more efficient the process. In addition to this, a number of other processes in the plants have also been optimised. These include the effectiveness

The blades of large steam turbines can be as tall as a man in the low-pressure area.



Schematic of carbon scrubbing. RWE is constructing a pilot system at its Niederaußem power plant.

of steam generation (in the boiler), the pressure in the condenser, the regenerative heating of the feed water, the internal energy consumption and the flow at the end of the steam turbine. The efficiency can be increased, for example, by designing the last stage (low pressure) in this type of steam turbine with as large a cross section as possible; the length of the turbine blades must also be correspondingly increased. However, the high mechanical stresses push materials technology to its limits: such a turbine generally rotates with 1,500 or as the case may be 3,000 revolutions per minute.

"We have already exhausted process-related improvements to a large extent today," said Kather. "Basically, if we want to further increase the efficiency, we must do so by increasing the steam parameters." In the power plant generation being constructed today, the steam has a temperature of around 600 °C and a pressure of around 280 bar. The next generation in contrast will see these figures increase to 700 °C and 350 bar, respectively. The aim is an efficiency of 50 %. This progress will only be possible if all process-related potentials are addressed anew by research – by improving the details as required in the various plant components. This includes new materials for the low-pressure blades (titanium-aluminium alloys) and for the steam generator with its steam control valves (nickel-based alloys).

Development work on these topics is being pursued in a number of different places in Germany. One of the BMWi research programmes is concerned with testing materials that have the potential for use in power plants with a temperature of 700 °C in terms of their long-term behaviour and their behaviour under "real" corrosion conditions. In Mannheim, for example, a test loop for the 700 °C technology will be put into operation in 2009. It is hoped that this will provide important information on practical application. The energy company E.ON is going even further. In September 2007, E.ON announced its plans to build a 500-megawatt demonstration hard-coal power plant based on the new technology (700 °C and 350 bar) in Wilhelmshaven by 2014. It will be the first steam power plant that will go beyond the magical efficiency boundary of 50 %.

Using more renewable energies to generate electricity poses new challenges on the electricity market. A higher degree of flexibility and improved behaviour under partial loads are increasingly being demanded of conventional power plants. This naturally leads to new challenges for technology. Steam power plants must have fast start-up and shut-down times in the future and they must also demonstrate high efficiency and low emissions when operated below the maximum possible power. Researchers today make use of comprehensive modelling and simulation processes to investigate the behaviour of turbines and other power plant components under partial loads. In this way, they learn about flow conditions and can gain a better understanding of the impacts they have on the components.

Since lignite power plants tend to be situated too far away from conurbations, combined heat and power generation is generally ruled out in terms of improving energy utilisation. However, another technology is perfect when it comes to increasing energy utilisation: lignite drying with relatively low-grade so-called extraction steam from the steam turbine. Although this process generates slightly less electricity with the low-pressure area of the turbine, the heating value of the coal is improved, which means that overall the electrical efficiency increases by 3 - 5 %. This technology is being developed by a number of energy companies, each with slightly different approaches, with funding from BMWi.

Scrubbing carbon dioxide

Post-combustion capture involves scrubbing the carbon dioxide contained in the waste gas, where it accounts for 12 – 15 % after normal combustion, using what is known as an absorber. Following this, the "detergent" is then separated from the CO_2 (regeneration). In doing so, a highly concentrated CO_2 flow is created, which is then compressed under high pressure so that it can be fed into a downstream pipeline, which transports it to an underground storage formation. CO_2 scrubbing can be performed using liquid solvents. Organic substances such as amine are often employed in this process. A substance frequently used for this in the chemical industry is monoethanolamine (MEA). The amine is injected into the flue gas flow, where a chemical reaction causes it to absorb the CO_2 after which it is pumped into the regenerator. The solvent is regenerated there with the aid of steam at a temperature of up to 130 °C. The CO_2 is then separated from the solvent as a concentrated gas. After this, the amine is fed back into the system and re-used in the capture process.

The regeneration process consumes a lot of energy. At least 60 – 70 % of the steam that flows into the low-pressure area of the power-plant turbine must be diverted for it. It is therefore important that the CO_2 scrubbing process be coupled with the actual steam power process in the most optimum manner possible as this will keep efficiency losses to a minimum. The steam turbines must be designed and tailored for the subsequent capture process.

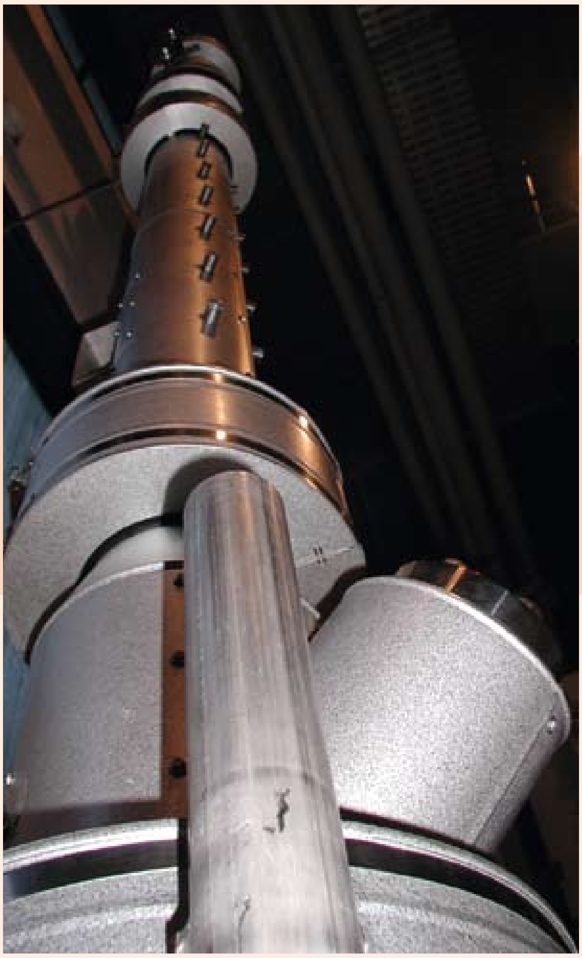
Capturing carbon with the aid of amine scrubbing is a process that is already established in industrial applications. A number of power plants based on this principle can be found throughout the world. In other words, we can fall back on existing experience. However, the framework conditions of existing plants are completely different to those of coal-fired power plants (gas composition, volume flows, impurities). Before this technology can be applied in coal-fired industrial power plants, there is therefore a significant need for development.

Research activities in this field, for example, are concentrating on developing and testing new solvents or mixtures of solvents, which require less steam for their regeneration and therefore decrease the energy demand. Another objective is to achieve a greater loading of the detergent with carbon dioxide: absorbed CO_2 per volume should be as high as possible.

A test facility for CO_2 scrubbing downstream of a lignite power plant will be built shortly at the RWE power plant in Niederaußem with funding from BMWi. This should provide important information on the long-term behaviour of different detergents under power plant operation conditions.

Absorption is also possible using dry processes, for example with calcium oxide, which is readily available in the form of limestone and is therefore inexpensive. Experience in this process has already been gained in industrial facilities where sulphur dioxide is separated from flue gases. In the case of carbon capture, however, the calcium compounds must be regenerated to keep the amount of limestone used to a minimum (the fabrication of calcium oxide from limestone also produces CO_2). A process known as carbonate looping has therefore been invented to deal with this. However, there is still a great need for development here. The next few steps will involve constructing pilot power plants, which will allow the different absorbents and absorption processes to be tested.

"Although downstream scrubbing leads to the highest efficiency losses compared to the oxyfuel process and IGCC with upstream carbon capture, it still has a huge advantage because it is based on the



A pilot power plant based on the oxyfuel process with rectification of the flue gas in order to obtain purity of the highest level at Dresden University of Technology.

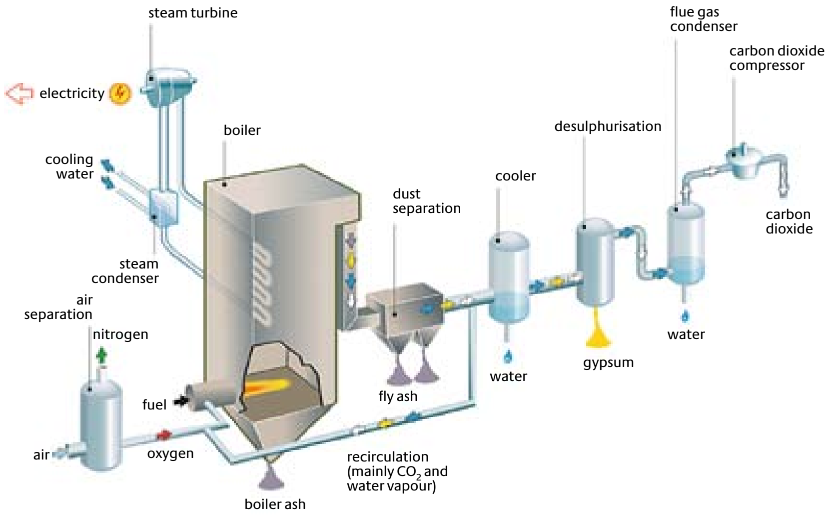
very reliable steam power process," summarised Alfons Kather, spokesman of the COORETEC advisory board. "This keeps the risk of something not working in the power plant process during the course of development work to a minimum." Another advantage is that this process can be integrated into existing power plants. A disadvantage of this process, in addition to the high efficiency losses, is the consumption of liquid detergent because this is permanently lost as a result of chemical reactions with certain components in the flue gas. One objective of development work is therefore to minimise the consumption of the detergent by improving the purity of the flue gas.

Combustion using oxygen: the oxyfuel process

A completely different method of capturing carbon is the oxyfuel process, which is also based on the steam power process. The nitrogen contained in the air that is to be supplied during the combustion process is extracted with the aid of an air separation unit: this means that almost pure oxygen is then fed into the combustion process. As a result, the flue gas is composed almost entirely of steam and carbon dioxide. The CO_2 concentration is elevated from the normal level of around 15 % to 66 % due to the fact that there is no atmospheric nitrogen to dilute it. Since the combustion of coal with pure oxygen gives rise to very high temperatures, around two thirds of the flue gas must be cooled, fed back into the burner and mixed with the oxygen before it can be fed into the combustion chamber.

When the resulting flue gas is subsequently dried, the CO_2 concentration rises to around 89 %. The level of impurities – namely, excess oxygen, argon, small quantities of nitrogen, sulphur dioxide and nitrogen oxides – contained in the gas is 11 %, which is still much too high for underground storage. Today, it is expected that oxygen, sulphur dioxide and nitrogen oxides in particular will cause problems if the CO_2 contaminated with these substances is transported through the pipelines and then stored as planned in underground geological formations. They could cause corrosion in the pipelines, and there is also a danger that undesired geochemical reactions could occur in the reservoirs.

This is the reason why impurities should be removed and the CO_2 concentration should be increased using additional measures, leaving us in the end with a maximum of 1 – 2 % impurities. One method of achieving this is so-called cryogenic liquefaction. This involves cooling the flue gas under pressure down to around minus 50 °C. This produces pure liquid carbon dioxide, which can then be captured. The greatest proportion of impurities in this case remains in the non-liquid flue gas, which is then emitted into the environment with the waste gas from the power plant. There is still some CO_2 contained in this – as is the case with other separation processes – meaning that around only 90 % of the carbon dioxide is actually captured. The liquid CO_2 phase, however, has a purity of between 98 and 99 %. "Based on current information, this should be sufficient to transport the carbon dioxide without any problems and to feed it into a storage formation," according to Alfons Kather.



Schematic of the oxyfuel process.

To what extent impurities in liquid carbon dioxide – and in what concentrations – could cause problems in final storage, for example through interactions with geological formations, is currently being investigated within the framework of COORETEC (see "Carbon storage" on p. 73). If it should be ascertained, for example, that the remaining residual concentrations of pollutant gases are intolerable, they must be eliminated using suitable flue gas purification processes. However, this would then mean further efficiency losses. Tests on flue gas purification are currently being conducted at Dresden University of Technology in a pilot power plant (see photo on p. 69).

The types of problems associated with the oxyfuel process that must be solved by research are demonstrated by the example of what is known as excess air. When coal is burnt, more oxygen must be added than is actually needed from a purely chemical point of view. The reason for this is that the supply of pulverised coal and its distribution in the combustion chamber cannot be controlled or measured precisely enough to allow the air or oxygen supply to be exactly adjusted. If coal is burnt with too little oxygen, it does not burn in its entirety, and corrosion phenomena appear on the walls of the combustion chamber. In today's power plants, the excess oxygen that is added to be on the safe side is at least 17 %. In previous research, it was calculated that from 1 to 5 % would be enough but these results are now considered outdated. The values held solely for tests on a laboratory scale and not for large-scale industrial power plants.

Excess oxygen is extremely important in the oxyfuel process. The less O_2 that is added as excess, the lower the level of impurities in the end product after capture – in other words, in the liquid carbon dioxide. Studies at Hamburg University of Technology in connection with COORETEC have shown that an excess of 15 % is necessary but that this is also sufficient. This value has been generally accepted as standard.

The pilot power plant in the "Schwarze Pumpe" industrial area (see start of chapter) is therefore extremely important in as much as this is where the first real operational processes are being investigated and open questions are being addressed. The plant simulates all of the decisive components on a small scale. In other words, it comprises a steam generator, air separation unit, flue gas purification system and a carbon capture process. Only in this type of plant can we clarify whether the integrated oxyfuel combustion process could hamper the flexibility of the power plant as a whole, in other words, its ability to adapt to frequent load changes.

A future power plant equipped with oxyfuel combustion would have a much lower efficiency than is common today. After all, air separation, carbon capture and the partitioning of impurities all cost energy. The efficiency would therefore sink to around 36 %. Such is the – with today's technology unavoidable – price for reducing the greenhouse gas of carbon dioxide. Progress in the future will be possible if the air separation and carbon capture processes are optimised with respect to energy, on the one hand, and if the entire oxyfuel process is integrated as efficiently as possible into the steam power plant process, on the other.

The second generation of this technology has already been born and is being developed under the keyword of oxycoal. This technology replaces the previously used energy-intensive process of air separation with a membrane process. A ceramic membrane module that only allows oxygen to pass through it at a temperature of more than 700 °C is used. Nitrogen and oxygen are separated from each other in this way. The process has an additional advantage: a proportion of energy required can subsequently be recovered by using the hot air from which the oxygen has been removed in a turbine to generate electricity. At the moment, research in this area is concentrating on developing suitable membrane modules for industrial application. These membranes must be durably stable and allow a sufficiently high level of oxygen to be captured. Moreover, a number of structural issues must be clarified in order, for example, to guarantee leak-free operation even for temperature fluctuations.

Another suitable process – albeit also one that will only be fully operational in the distant future – is known as chemical looping combustion (CLC). In contrast to conventional combustion where air or oxygen must be added, metal oxide is used here as an oxygen carrier. Nickel oxide and iron oxide are two examples. In this process, air separation and the combustion process occur in two different reactors connected in parallel. In one of the reactors (oxidation reactor), the metal is oxidised and thus absorbs the oxygen from the air. In the other reactor (combustion reactor), the metal releases the oxygen and transfers it to the fuel which is thus consumed. The metal on the other hand is not consumed and can subsequently be transferred back to the oxidation reactor. Ideally, the end products of the combustion process should be just steam and carbon dioxide, which can then be accordingly separated. The advantage of this process is that the production of oxygen using such chemical processes requires much less energy than conventional air separation. It is expected that the CLC process can be used in both a steam and combined cycle power plant. However, much research is still required in this area. The process will therefore most likely only be ready for application after 2020.

Coal is gasified

The process has been around for a long time but only in the last few years has it become of interest for the generation of electricity once again: coal gasification in combination with a gas or steam turbine power plant (integrated gasification combined cycle, IGCC for short). Coal is transformed into a fuel gas in a combustion process, which – after a purification process – can be used to drive the gas turbine in a combined cycle process. “The process is going through a real renaissance with regard to the greenhouse gas of carbon dioxide,” believes Alfons Kather. The reason: “Carbon capture can be integrated into this process relatively easily.” An advantage is that this technology – albeit without capturing carbon – is already being tested in a number of different locations worldwide.

In addition to a high efficiency potential of more than 50 %, coal-fired power plants based on the IGCC technology keep efficiency losses caused by capturing carbon dioxide to a minimum. Physical scrubbing processes, for example with cryogenic methanol, can be used for this purpose – a proven industrial technique in the chemical industry. Even with this capture system, such power plants – at least theoretically – are still capable of achieving an efficiency of more than 40 %, around 2 – 3 % more than power plants with the two other capture techniques. Another advantage of the technology is that it is not just used to generate electricity but also to produce storable energy carriers such as hydrogen, methanol, or synthetic natural gas (SNG) and indeed raw materials for chemical production.

A range of IGCC power plants without carbon capture already exist throughout the world and some of them have been in operation for a number of years. In some locations, technology developed in Germany is also in use. The basis of IGCC technology is being investigated in a variety of projects funded by BMWi.

An impressive pilot plant, for example, can be found on the campus of the TU Bergakademie Freiberg. A whole range of basic and applied research activities are underway here in order to improve the design of the next generation of IGCC plants.

Pilot power plant for high-pressure partial oxidation at TU Bergakademie Freiberg.

The biggest problem associated with the current technology is the lack of reliability in comparison to other power plant concepts. The German power supply company RWE is planning to build an IGCC demonstration power plant with integrated carbon capture. It is expected that this plant will be capable of achieving a net power of around 330 megawatts and that it will go into operation in 2014 on the outskirts of the city of Hürth in the Rhineland.

"In the past, we have failed to really exploit the technical potential of this technology," said Alfons Kather. "However, if we concentrate on certain weak areas and find new solutions for these, the technology would then be more than promising." This is true of the cooling of the raw gas, for example. After the gasification process, the fuel gas is initially too hot for the subsequent essential purification steps and must therefore be cooled. Only in a cooler state is the raw gas ready to go through a series of chemical and physical processes in which it is purified as required for use in the combustion process in a gas turbine. A reliable way of cooling the gas, but which simultaneously causes heavy efficiency losses, is a process known as quenching. Quenching involves injecting cooling water into the gas. The latest developments are based on partial quenching of the synthesis gas, which allows improved efficiency.

A number of challenges must be overcome before IGCC technology can be combined with carbon capture on an industrial scale. For example, in order to capture carbon dioxide, steam is added to the raw gas to transform the CO contained in it into CO_2 and hydrogen. The carbon dioxide can then be captured and stored using conventional technologies. The synthesis gas in this case is composed predominantly of hydrogen. This gives rise to a new challenge because the combustion of hydrogen is a demanding job for the developers of gas turbines. Different gas turbine manufacturers have already begun working on this task.

After all, the ultimate aim is to optimise combustion technology in order to increase fuel flexibility so that different energy carriers such as lignite, hard coal or biomass can be used in the same plant and to simultaneously increase the efficiency. These and other development objectives will be realised within the framework of COORETEC in close cooperation between research institutions, component manufacturers and power plant operators. If an IGCC plant is to be used to generate liquid or gaseous synthetic energy carriers (coal to gas (CTG) or coal to liquid (CTL)) in addition to electricity, further stages of development are necessary. All of the individual components must be in tune with each other and

In the integrated gasification combined cycle (IGCC), coal is transformed into a fuel gas that can then be used to drive the steam turbine in a combined cycle power plant.

integrated into the overall process in such a way that the power plant can be operated more efficiently, more reliably and with a much higher degree of flexibility.

Carbon storage

When the combustion product CO_2 is captured in the power plant, it must either be put to use in another way or stored so that it does not enter the Earth's atmosphere. One option is to pump it as a liquid into underground geological strata, such as porous sandstone formations. In principle, carbon dioxide can be stored underground as a gas, a liquid or in what is known as a supercritical phase. Its physical state depends on the pressure and temperature of the environment; both increase with increasing depth. Below around 700 metres, the pressure is so high that CO_2 can be optimally absorbed by porous reservoir rock. The options for storing CO_2 underground in the Federal Republic of Germany include exhausted gas fields in North Germany and deep saline aquifers. Their capacity alone for absorbing carbon dioxide has been estimated by the Federal Institute for Geosciences and Natural Resources (BGR) to be around 20 billion tonnes. For comparison: a large lignite power plant emits around 8.4 million tonnes of carbon dioxide each year.

Only when we can say with certainty that stored carbon dioxide can be kept out of the atmosphere over a long period of time will it make sense to separate the gas in power plants. The first pilot projects on carbon capture are already underway and research into long-term storage is being intensified and accelerated. Technical processes for injecting carbon dioxide deep underground are already in use throughout the world. In addition to processes that aim to increase the yield from oil fields, they are also used in some natural gas fields (North Sea, Algeria) in order to feed the CO_2 produced during natural gas extraction back underground. In Germany, natural gas has been temporarily stored underground for years.

Schematic of underground carbon storage. Storage options include exhausted oil and gas fields and saline aquifers.

Despite this, the permanent storage of such large quantities of carbon dioxide poses new and more complex challenges which must first be overcome.

Researchers and developers find it helpful to take a look at the natural carbon dioxide reservoirs that exist throughout the world in various geological formations. Carbon dioxide has been sealed away from the environment in some of these for millions of years. On the other hand, CO_2 is also naturally released in many places by volcanism or geysers. An impressive example of such natural CO_2 sources is Yellowstone National Park in the USA, where around 16 million tonnes of CO_2 are released into the atmosphere every year. This example makes it clear that potential carbon dioxide reservoirs must be chosen with great care.

Within the framework of COORETEC, all of the important processes between the power plant and the storage formation are being studied in detail. Numerous questions have to be addressed. What problems could be caused in pipelines, pumps or compressors as a result of impurities in the gas? Could corrosion phenomena appear in these power plants or in the boreholes? How can the continuously increasing pressure with increasing depth be dealt with underground? What geochemical processes occur when the carbon dioxide flows into the geological formations? How can the reservoirs and boreholes in particular be securely sealed so that no carbon dioxide can leak out and make its way back to the Earth's surface?

Suitable compressors for compressing carbon dioxide, transporting it over large distances in pipelines and then pumping it deep underground have been developed for a number of years in Germany. The company MAN Turbo constructed an eight-stage geared compressor that compresses the gas to a final pressure of 187 bar. MAN is involved in a project in North Dakota (USA) in which the CO_2 produced in an industrial coal gasification plant is pumped through pipelines to oil fields in Weyburn in the Canadian province of Saskatchewan. There, it is used – when compressed into the reservoirs – to increase the oil extraction pressure and therefore achieve an improved yield and a longer lifetime for the oil field. The corresponding pipeline is 350 kilometres long and has a pipe diameter of 36 centimetres. Every day, around 7,000 tonnes of carbon dioxide are currently pumped through the pipes and injected underground. According to information from the operators, this increases the extraction yield of oil by 18,000 barrels per day.

A prerequisite for safe transport is the corrosion resistance of all components. This holds above all for the pipeline, the injection system with compressor and pump station, as well as for all parts of the injection instruments used to direct the gas underground. Carbon-dioxide-resistant chromium steel or resistant internal coatings, for example, can be used for this purpose. Once the injection process has been performed, in other words when the storage formation has taken up the maximum possible amount of gas, the borehole must be filled and sealed so that it is gas-tight. The leakage of CO_2 must be ruled out over long periods of time.

A series of current research projects is investigating whether underground storage formations in different locations in Germany have the potential for carbon dioxide storage. For example, as part of the EU CO_2SINK project headed by the National Research Centre for Geosciences in Potsdam (GFZ) with additional funding from the Federal Government, carbon dioxide is being stored underground for the first time on the European mainland in the town of Ketzin in Brandenburg. The project began in autumn 2007, and over a period of two years, a total of around 60,000 tonnes of high-purity carbon dioxide will be injected into a saline aquifer below a former underground gas reservoir at a depth of around 700 metres. The behaviour of the gas will be monitored and investigated with the aid of two neighbouring boreholes.

In order to be able to estimate how much carbon dioxide a certain rock can take up, the storage efficiency must be analysed. This indicates the volume that can be filled with CO_2 as a proportion of the total pore volume of the storage formation. Capacity estimates assume an average storage efficiency of 20 %. Reservoirs are only suitable for this type of storage, however, if they have geological covering strata (clay, gypsum or halite) which seal the storage layer from the Earth's surface. These must not have any untight areas caused, for example, by former boreholes or geological features.

Underground, chemical processes occur between the gas and the geological material. The injected CO_2 can, for example, lead to the formation of minerals such as carbonates. In the worst case scenario, compounds could be created that could be washed out and jeopardise the stability of the storage formation. Possible chemical reactions are affected, on the one hand, by the purity (or to put it another way, the type and concentration of impurities) of the carbon dioxide that is to be stored, and on the other, by the composition of the pores, the rock in the reservoir and that in the top layer. Such processes must be thoroughly investigated in the near future. Laboratory tests, for example, are planned for this purpose using rock as found at the various planned sites.

Outlook

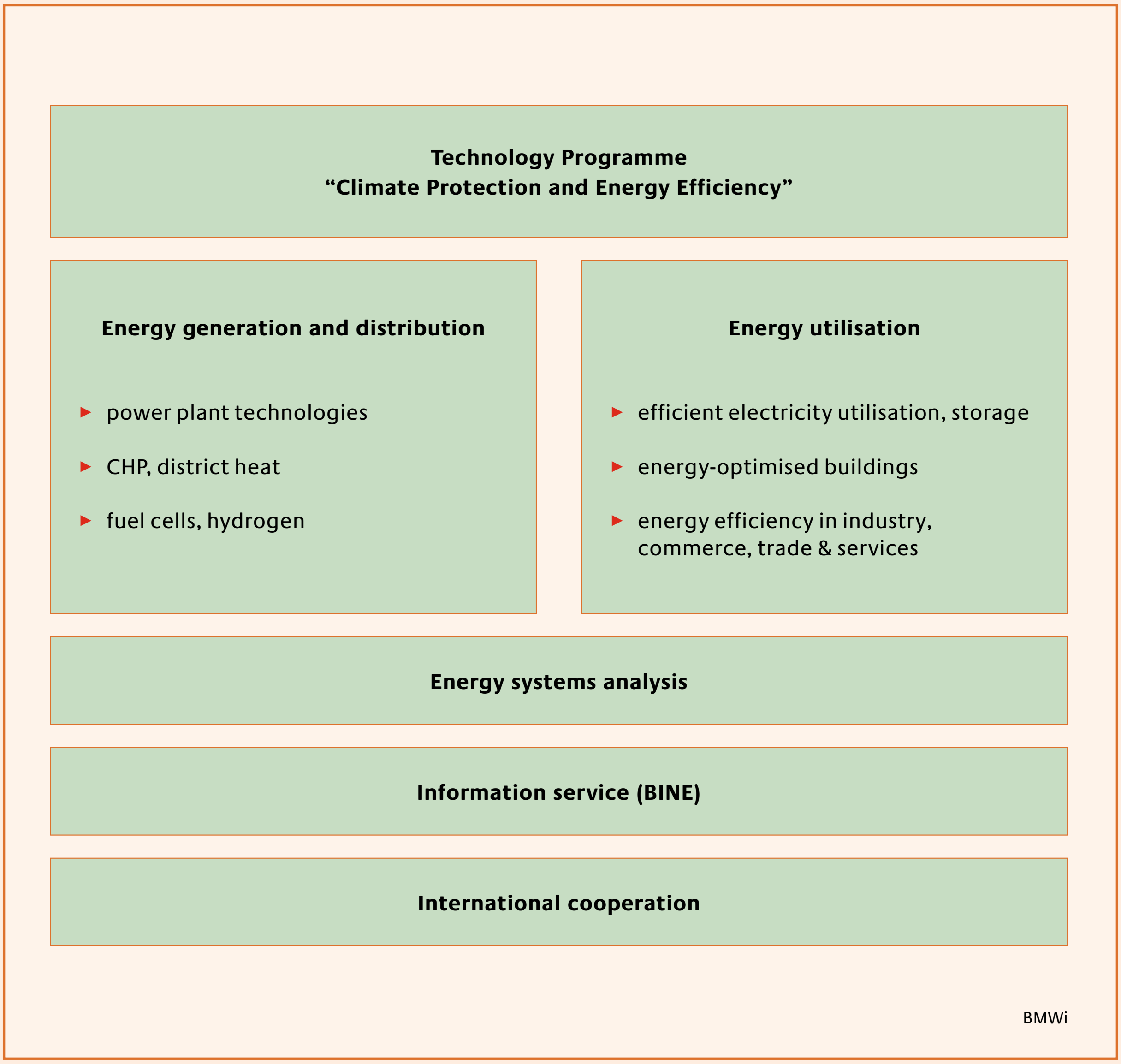
The European Commission believes that by increasing the efficiency of power plants and carbon capture and storage (CCS) technologies, a significant contribution will be made to decreasing global emissions. These technologies play an extremely important role in the Federal Government's Integrated Energy and Climate Programme. Furthermore, in the Cabinet report from September 2007 on "The level of development and prospects for CCS technologies in Germany", the Federal Government outlined where they stand with regard to the development of CCS technologies. The documents can be downloaded online at www.bmwi.de.

The International Energy Agency (IEA) has estimated the potential for reducing CO_2 emissions by 2030 to be around two billion tonnes per year. In a report in 2005 for the United Nations, the Intergovernmental Panel on Climate Change (IPCC) predicted that by 2050 between 20 % and 40 % of global carbon dioxide emissions will be captured and stored "at acceptable prices".

Germany is among the world leaders when it comes to research and development activities that play a role in this context, as COORETEC spokesman Professor Alfons Kather puts it: "When it comes to combined cycle processes, the companies Siemens and Alstom are ahead of the rest. With regard to carbon dioxide scrubbing, Japan is currently top but Germany will catch up quickly. In terms of oxyfuel, nobody is as advanced as us. And finally, Germany is the first country in the world to have a power plant based on IGCC technology with carbon capture."

Cross-cutting measures

In addition to research and development projects in the six areas of "modern power plant technologies", "CHP, district heating", "fuel cells, hydrogen", "efficient electricity use and storage", "energy-optimised buildings", and "energy efficiency in industry, commerce, trade and services", BMWi supports interdisciplinary measures within the framework of its technology programme "Climate Protection and Energy Efficiency" (see graphic below). This includes energy systems analysis, the distribution of information and international cooperation.



Fields funded within the BMWi technology programme "Climate Protection and Energy Efficiency".

Energy systems analysis and the EduaR&D project

An important objective of government research funding has always been to make decisions on priority areas of funding and those of less urgency. This is all the more urgent as every tax payers' euro invested in research must be put to use as efficiently and selectively as possible.

An instrument of scientific policy advice used as a basis for such decisions is energy systems analysis. It does not just provide results that are taken into account in decisions made by politicians on climate protection measures, technology policy or energy research objectives. Energy systems analysis is in itself also an object of energy research funding. This ensures that it can develop new methodological approaches and that its infrastructure – partially built up using previous funding – can be safeguarded and further expanded.

In general, systems analysis is concerned with goal-oriented studies on structures in the economy, the public sphere and in society itself. It makes use of analytical models – in which the objectives of the systems studied are formulated and defined together with the evaluation criteria – as an aid to selecting possible alternative courses of action, evaluating cost and benefit aspects, and performing sensitivity analyses and impact assessments.

Between 2004 and 2007, systems analyses were performed on BMWi project funding as part of the funding activity known as "Energy data and analysis R&D" (EduaR&D). This focused on the development and application of systems analysis instruments in order to set priorities in energy research funding.

EduaR&D aimed to create a basis for identifying and evaluating promising emerging energy technologies that could help the German Federal Government achieve its energy policy goals. The project findings are being used to optimise the funding policy in the field of energy research, to deploy funds more efficiently, and to reinforce systems analysis as an instrument of scientific policy advice.

After a call for proposals in spring 2004, a total of six projects were approved. Two of these projects were concerned with overarching questions associated with systems analysis and methodology in order to develop decision-making criteria for an efficient funding strategy for research and development as well as concepts for setting priorities in energy research. Four other projects conducted technology analyses and evaluations in the funding areas of "fuel cells, hydrogen", "heat and power generation" and "buildings".

In the critical discussion of the EduaR&D project findings, it was revealed that predictions on suitable development lines depended heavily on the technology investigated. While the formulation of concrete development goals is relatively easy for technologies that are at an early stage of development (such as fuel cells, power plants with carbon capture and storage), this is much more difficult for mature fields (such as passive houses or industrial combustion plants). Some examples of the findings of EduaR&D are that

- the incorporation of competing and/or commercially available technologies is essential for the comparative analysis of the development potential of innovative technologies,
- the observation of developments abroad can be helpful in terms of recognising undesirable developments in good time,
- the cost degression potential of new technologies is still neither methodologically nor empirically well-founded,
- the economic viability of new technologies is moreover strongly influenced by the assumption of future energy and fuel prices, and
- external costs (such as how emission certificates are to be issued) influence the ranking of technologies.

Overall, it was ascertained that the great potential associated with systems analysis can also be expanded to include other subject areas. From an expert's point of view, for example, it would be interesting to apply the EduaR&D findings to prepare long-term technology scenarios or to evaluate technology in the field of renewable energies.

Dissemination of information
BINE Information Service

The functions of energy research policy also include circulating the results of research, development and demonstration projects in order to accelerate the introduction of new technologies on the market. A prerequisite for this is a targeted transfer of knowledge to the disseminators and users of research results. This includes the processing of technical data correctly, and compiling these for the user in a comprehensive and compact manner within a short period of time.

In its role as a leading government department for energy research in Germany, BMWi supports the targeted distribution of information and research results in the field of energy, particularly through the BINE Information Service, which is a service offered by FIZ Karlsruhe, as an interface between research and industry.

BINE is the central, nationwide information office for energy research findings in the fields of “energy-efficient technologies” and “renewable energies”. The BINE editorial team conducts searches for current scientific and technical information in the research sector, processes this information according to target group and publishes it in various BINE information series:

- “project info” provides current information on the results of research and demonstration projects
- “topic info” summarises cross-project findings from research and application
- “basic energy info” focuses on the basics of selected energy topics
- the book series “BINE information packages” documents current research findings and application know-how, which can be employed in practice.

The well-respected BINE publications are systematically linked on the Internet to other sources of information and they are supplemented by the BINE publishing hotline. In addition to the BINE Newsletter, the range of electronic information also includes web portals that are created and continuously updated by BINE.

The primary target groups for the specialised information provided by BINE are small and medium-sized enterprises, experts, decision makers, investors and disseminators of information including those in the education sector.

BINE “info” brochures focus on energy-efficient buildings, industrial processes and best practice examples.

Outlook

BMWi will continue to support the distribution of information through BINE in the future, and intends to intensify the further development and expansion of the range of information offered by BINE. Particular attention will be focused on integrating new methods of distributing information and new media, as well as on the incorporation of other institutions and organisations from the relevant sectors in order to improve the impact of disseminators of information. Supporting international information transfer represents a new priority area.

BINE web services:

www.bine.info
www.energie-projekte.de
www.energiefoerderung.info
www.enob.info
www.eneff-stadt.info
www.eneff-waerme.info

International cooperations in energy research

EU funding in the field of energy

The EU provides funding for research and development on the basis of framework programmes (FPs), which run for a number of years. The foundation for FPs was laid by the Treaty establishing the European Community, articles 163 – 173. The objectives are to reinforce the scientific and technological foundation of industry, to promote the development of international competitiveness, and to expand the European Research Area (ERA).

The Seventh Framework Programme (FP7) was launched at the beginning of 2007 and will run until 2013. A total of € 53.2 billion have been made available for FP7. Non-nuclear energy research is one of the ten thematic areas of the programme for which € 2.35 billion have been set aside. Applications for research projects can be submitted on the basis of calls, which are published each year. The Programme Management Committee for Energy, in which BMWi represents the German Federal Government, supports, provides advice and monitors the European Commission in preparing and processing the calls.

In order to benefit from the advantages of the synergy between national and European funding policy, BMWi is involved within the framework of the FPs in European technology platforms, such as “Zero-Emission Fossil Fuel Power Plants (ZEP)” and “Electricity Networks of the Future”, as well as in ERA-NETs (“Hydrogen and Fuel Cells – Hy-Co” and “Fossil Energy Coalition – FENCO”).

In order to guarantee the success and efficiency of German applicants, it is extremely important that information on the contents, procedures, and terms and conditions of EU funding programmes is made available to companies, research institutions and government agencies in Germany as fast and as comprehensively as possible. This is where the Federal Government’s National Contact Points (NCPs) come into play. BMWi entrusted Project Management Jülich (PtJ) with the task of implementing a National Contact Point for Energy. This NCP is responsible for the field of energy in the EU’s Seventh Framework Programme and for the programme known as Intelligent Energy – Europe (IEE).

As a member of the NCP network, NCP Energy provides specialist information and advice on a neutral basis. Furthermore, it cooperates on a European level with other information and consulting agencies on programmes launched by the European Union. NCP Energy aims to ensure that there is adequate participation of German partners in the European Union’s funding programmes in the field of non-nuclear energies and it is therefore in close contact with the European Commission.

As EU funding is allocated on the basis of annual work programmes and calls, and there are regular application deadlines, advice offered by NCP Energy on the topics involved and application procedures is extremely important for potential German applicants and disseminators of information. One of the dominant aims is to continuously improve the quality and efficiency of the applications submitted by German applicants and thus to increase the chances they have of receiving funding. Funding tends to be around 50 % of the total expenses associated with a research project. Experience from earlier framework programmes has shown that 15 – 20 % of German applications are successful, in other words almost every fifth German application is awarded funding by the EU.

In terms of providing advice, NCP Energy works hand in hand with local disseminators of information. These include, for example, the Chambers of Industry and Commerce, EU offices at universities and other consulting agencies. The NCP organises its own information and advisory events and its employees are also available for events organised by other organisations. Support is also offered for applicants looking for suitable competent partners to cooperate with on a research project. NCP Energy, just like all other NCPs, is funded by the Federal Government and the services offered by NCPs are free of charge and do not represent any particular interest group. All inquiries are confidential.

International Energy Agency (IEA)

Germany was one of the founding members of the International Energy Agency (IEA), which came into being in 1974. Today, IEA offers its 28 member countries a broad forum for the joint coordination of

Flags of the EU member states in Brussels.

important energy issues. Moreover, it is a platform for international research cooperations focusing on the fields of renewable energies, fossil energy carriers, energy efficiency, and nuclear fusion. In principle, IEA research cooperations are open to all countries that believe it is important to cooperate in the area of the development of energy technologies. The IEA is currently aiming to consolidate the participation of countries such as China, India and Russia.

From the very start, Germany actively participated in the IEA research and technology programmes – science and industry are now involved in 27 of the total of 41 ongoing IEA projects. Funding is granted for the following:

- the development of new technologies that will contribute to a global, sustainable and environmentally friendly energy system,
- an intensive international exchange of information on the latest developments in each of the technology fields,
- diffusion and market introduction on the basis of the very advanced level of development that energy technologies have achieved in many areas today, and
- resolving problems associated with global climate protection, particularly greenhouse gas emissions in the energy sector.

Germany continues to be involved in the energy research and technology sector through participation in ad hoc international groups offering advice on specific issues such as the role of basic research. In addition, German experts give presentations at IEA international workshops and they contribute regularly to many of the IEA publications.

All activities in the field of energy research are coordinated by the Committee on Energy Research and Technology (CERT). The Federal Government is represented by BMWi in CERT. BMWi is supported in this function by Project Management Jülich (PtJ).

The contacts, experience and knowledge gained through IEA cooperations are used for project activities within the framework of the Federal Government's Fifth Energy Research Programme, to further develop national research and funding programmes and to analyse and improve energy research policy strategies in the light of international development.

Multilateral energy research initiatives

BMWi also participates in multilateral energy research initiatives, such as the Carbon Sequestration Leadership Forum (CSLF) in the field of power plant technologies for carbon capture and storage and the International Partnership for the Hydrogen Economy (IPHE) for hydrogen technologies.

The prospects of energy research for more energy efficiency

by Eberhard Jochem

Without investing a single taxpayer's euro in research on new technologies, energy losses in the industrial nations could be halved by using only the profitable technologies that are already available today. Despite this positive opportunity, in the face of challenges posed by climate change and limited oil production options, in principle nothing would change: by 2040 at the latest, the global energy demand would increase once again due to the ever-rising global gross domestic product. Is there new potential for increasing energy efficiency over the next few decades by a factor of two in relation to today? And how quickly will non-fossil primary energy carriers be available to bring global CO_2 emissions to a standstill in 20 years or so, and subsequently reduce these emissions to 1 tonne of CO_2 per capita by the end of the century? (Germany today: 10 tonnes of CO_2 per capita per annum).

Efficiency as a challenge

These questions direct attention to energy research. In the OECD countries, budgets for energy research have declined by more than 50 % since the end of the 1980s to around ten billion dollars in 2005. Today, public research funding amounts to the equivalent of a cinema ticket per capita per annum. Research expenditure in the field of energy is in fact generally covered by the capital goods industry. In addition to the question of the amount of money invested in research, another question that must be answered is how efficient the euro invested in energy research actually is. It would appear that there is much room for improvement on the part of all actors in relation to this. Here is a small selection:

- The institutional funding of large research centres in the Helmholtz Association was reorganised at the beginning of the decade and is now still undergoing personnel restructuring. It will undoubtedly take a few more years before the research centres are really ready to tackle the challenges of the future.

- Cooperations between industry and higher education institutions still have to be optimised. They tend to be primarily determined by the department's expertise and willingness to cooperate rather than the amount of state funding available.

- The creation of expertise is a long-term task. By increasing state funding for energy-related basic research at universities and other research institutions, cooperations with industry will only be stimulated and technology transfer will be accelerated from the laboratory to the market in the medium term.

- By exchanging more information (including teaching modules) and cooperating more, the efficiency of energy research will be increased in both universities and research institutions. This will also avoid duplication of work. In doing so, it is important that scientific competitiveness is not curtailed, but goal orientation and complementary research should be agreed upon in an organised manner.

- In 2006, the International Energy Agency (IEA) ascertained that the largest contribution to CO_2 emissions reduction (around two thirds) is expected from increased energy efficiency within the next 25 years. At ETH Zurich in 2003, scientists postulated that the use of energy could be improved by a factor of five by the end of this century. This focus on the use of energy must be adopted by energy research policy, which has concentrated on the idea of expanding the energy supply for the last fifty years.

- The efficiency of energy research can therefore certainly be improved in many places by focusing on certain topics and cooperating more with the capital goods industry and the chemical industry. We should also acknowledge researchers more and restructure financial input according to the various subject areas.

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Opportunities and risks associated with energy research

In the fields of energy-optimised buildings, renewable energies, highly efficient thermal power plants and vehicle technology, research in Germany holds its own very well in international competition. With regard to the latter two technology fields, however, there is a danger that the state-funded applied basic research at universities will no longer be able to keep up with industrial research. Even the sheer size of pilot plants exceeds the dimensions of research laboratories on an institute level.

The division of energy research in Germany amongst four Federal ministries (Economics and Technology; the Environment, Nature Conservation and Nuclear Safety; Education and Research; Consumer Protection, Food and Agriculture) and the associated division of work between the departments are also the result of negotiations by coalition governments over the past twenty years. A high degree of consensus among the government departments means huge advantages in terms of consistent funding for new technologies from the research laboratory right through to market introduction. Dividing the work in this way gives rise to a potential for accelerating innovations in the four departments.

Systemic research that takes the entire energy chain into account can be promoted if the departments work together hand in hand. From an energy efficiency point of view, however, research related to new physicochemical and biotechnological processes, as well as materials science, should concentrate on stronger "radar tasks". Both of these examples illustrate the opportunities afforded by cooperations between the ministries, on the one hand, and on the other, by the targeted orientation of departmental research in terms of social needs regarding new generic technologies.

Climate policy suffers under a global discussion that focuses exclusively on the costs of avoiding CO_2 and disregards adjustment and damage costs. This one-sided nature is also caused by economic modelling approaches, which still often fail to include information on adjustment and damage costs. This is where the challenge lies for the Federal Government and the EU Commission. They must be able to justify their (rightly) ambitious goals with arguments in the general global context.

European and international research cooperations are frequently only moderately successful because of the balanced national composition of the projects receiving funding. Purely national or binational and trinational funding of research partners with strengths that complement each other would ensure that every euro invested in research is more effective.

The Federal Government and the EU Commission need to whole-heartedly take up the technology initiative suggested by the US Government in addition to the Kyoto process. Compared for example to emission certificates, new technologies can actually help to completely avoid harmful emissions and conserve resources.

An (optimistic) summary

The challenges involved in changing today's global energy system – and with this, those facing energy research in all of its interdisciplinary facets – are gigantic. The problem is not a lack of technical ideas and solutions, but rather a lack of understanding amongst the actors in science, industry, and the government, as well as amongst the voters and consumers that these challenges must be addressed head on. For this process of seizing opportunities and exploiting options, it is essential that communication, financial incentives and research platforms are facilitated. The first impacts of climate change and experience over the last few years, which has shown that securing the energy supply can hardly be enforced in a military fashion, will undoubtedly stimulate this necessary change of mindset.

It would appear that long-term, efficiently thought-out energy research is better in terms of realising goals. More tax revenue should be invested in this matter of concern than the value of an annual cinema ticket per capita. After all, the huge number of necessary changes in the entire global capital stock means that it is not just about energy research alone. What counts are technical and entrepreneurial innovations in all areas of an industrial society over the next few decades on the way towards a sustainable capital stock with significantly improved energy efficiency and a very high proportion of renewable energy sources in primary energy consumption.

Funding information

Within the framework of the BMWi technology programme "Climate Protection and Energy Efficiency", industry, universities and research institutes have the opportunity to apply for funding for excellent projects that make significant technological contributions to the remodelling of the energy system in terms of security of supply, economic viability and environmental compatibility. The main aim behind research funding is to mitigate the risks associated with new developments and to speed up the development of new technologies. Joint collaborative projects between science and industry also integrate the innovation potential of small and medium-sized business.

Project Management Jülich (PtJ) at Forschungszentrum Jülich is responsible for the technical and administrative coordination of the BMWi technology programme "Climate Protection and Energy Efficiency". More detailed information can be obtained from PtJ.

The review procedure for projects is performed in a two-stage process by BMWi and PtJ.

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