Federal Ministry
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Energie wende
Switch to the Future

The energy transition – a great piece of work

Innovation Through Research

Renewable Energies and Energy Efficiency: Projects and Results of Research Funding in 2015

Imprint

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Foreword

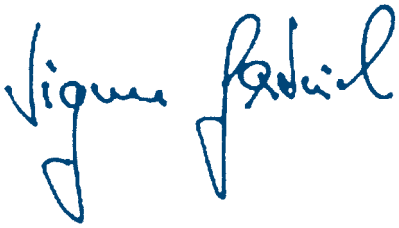
Energy research is a strategic element of energy policy. It makes an important contribution to the achievement of the energy and climate policy goals of the German Federal Government. The energy transition has laid the foundations for the sustainable restructuring of the energy supply system in Germany by 2050. The aim is to halve primary energy consumption and increase the proportion of gross energy consumption supplied by renewable energies to 60 percent. Needless to say, these ambitious goals can only be achieved as a result of significant technological innovations across the entire energy supply chain, from energy generation and distribution through to its utilisation.

Alongside the focus on individual technologies within the energy system, such as methods and processes for increasing energy efficiency, the integration of renewable energies, innovative energy storage solutions and modern grids, system-oriented measures that cross over different technologies are becoming increasingly important in the funded projects. The 6th Energy Research Programme "Research for an environmentally friendly, reliable and affordable energy supply" has created the basis for innovations through its consistent support of research and development in all of the technological fields mentioned above and across the entire value added chain.

The "Research and Innovation 2015" report presents the most important results of non-nuclear energy research funded by the Federal Ministry for Economic Affairs and Energy and explains the latest developments in the Energy Research Programme.

While you are reading this report, I hope that you gain many interesting and informative insights into this new world of interlinked energy technologies that we urgently require for the German energy transition.

Yours sincerely,



Sigmar Gabriel
Federal Minister for Economic Affairs and Energy

Research and development for the energy transition

The German Federal Government is on course for the successful restructuring of the energy supply system. Almost every third kilowatt hour of electricity consumed in 2015 was sourced from wind, solar, hydropower or bioenergy power plants. This means that renewable energies have become the number one source of energy for generating electricity in Germany. Wind energy has made the greatest contribution to achieving this record: It generated over 50 percent more electricity compared to the previous year. Yet the energy transition goes far beyond the electricity sector. Therefore, there is still a great need for technical innovations in all areas of energy generation, distribution and utilisation. As a result of its application-oriented measures in the Energy Research Programme, the Federal Ministry for Economic Affairs and Energy (BMWi) helps to ensure that innovations emerge through research and development and that they are successfully transferred from research laboratories and workshops to the market.

With this energy concept, the German Federal Government has the goal of creating an environmentally friendly, safe and affordable energy system in Germany. "With the German energy transition we want to demonstrate that it is possible in the long term to develop a highly efficient energy supply system that is primarily based on renewable energies. However, we can only be successful if the required technological innovations are realised through research and development activities. This also opens up new economic options that could contribute to the strengthening of the industrial base in Germany", summarises Rainer Baake, State Secretary at the Federal Ministry for Economic Affairs and Energy.

Five years after the energy concept was first adopted it is clear that the restructuring of the energy supply system is progressing well. It was possible to further reinforce the role of renewable energies as an important source of energy in 2015. They have now assumed the leading position by covering 30 percent of gross electricity production, while production from lignite (24 percent), hard coal (18 percent), nuclear energy (14 percent) and natural gas (almost 9 percent) has fallen once again. The integration of renewable energies into the supply system has also been achieved despite the already high proportion in the electricity supply system. Furthermore, Germany has great potential for increasing the volume of electricity generated by wind and

solar power, which was clearly underlined by a study published by the International Renewable Energy Agency (IRENA) at the end of 2015.

Increasing energy efficiency is equally as important as expanding renewable energies. The goal is to halve primary energy consumption by 2050. In this area, the German Federal Government has also been able to make significant progress with the approval of the National Action Plan for Energy Efficiency (NAPE) in 2014. Nevertheless, there is still great potential in the medium and long term for increasing energy efficiency that can often only be exploited through technological innovations.

Strategically funding research

In its 6th Energy Research Programme, the German Federal Government outlined the principles and focus of its funding policy. It envisages concentrating funding to an even greater extent on those technologies that could contribute to a sustainable energy supply system if successfully realised. Alongside research into energy conversion, such as photovoltaics and wind energy, this also includes issues relating to energy efficiency in buildings, cities and industry, and alongside energy storage solutions and grid technology, the integration of renewable energies into the energy supply system. The energy system of the future will have a significantly higher level of complexity than the current energy supply structure. Examining the interactions between all of those individual technologies mentioned above within an optimised overall system is thus becoming more and more important. From an organisational standpoint, the aim is to link national research activities within the European Union and with partner countries in the International Energy Agency (IEA) to an even greater extent. These goals were clarified in more detail once again for the various funding themes in the funding announcement “Research for an environmentally friendly, reliable and affordable energy supply” that was published on 8 December 2014.

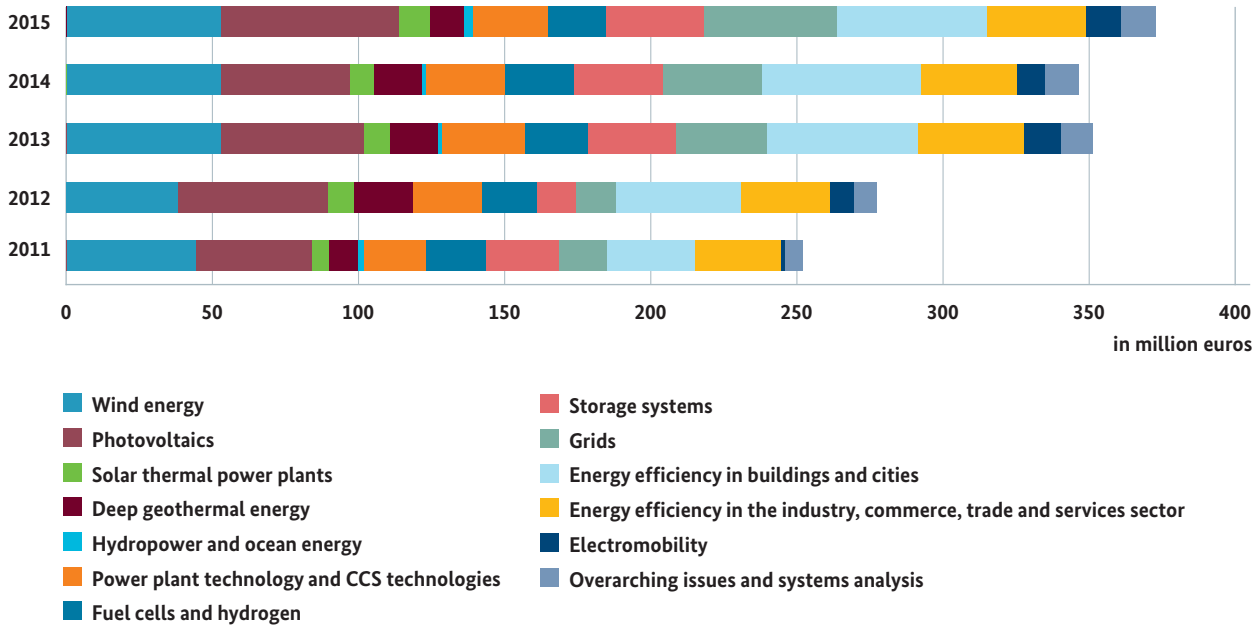
Research and development in 2015 in figures

The high level of emphasis placed on research and development in the area of renewable energies and energy efficiency was also reflected in 2015 by further increases in funding. The BMWi has supported a total of 2,793 projects with around 371.9 million euros of funding, 26.3 million euros more than in the previous year. As in the previous year, most of the funding was awarded to the areas of wind energy and photovoltaics, followed by measures for increasing energy efficiency in buildings and cities, storage technologies and grid infrastructures, as well as energy efficiency in the industrial sector. Other funding areas included geothermal energy, solar thermal power plants, systems analysis, fuel cells and research projects focussing on components in electric vehicles. In addition, funding was provided to projects in the area of conventional power plants that place an emphasis on highly flexible operation and also lower utilisation, necessary due to the increased use of volatile renewable energies.

Research projects in hydropower and ocean energy were funded in individual cases as previously. The total number of newly approved projects once again increased significantly: from 695 projects in 2014 with total funding of around 373.2 million euros to 939 newly approved projects in 2015 with total funding of around 548 million euros.

Renewable energies are now the most important source of electricity in Germany

Volume of funding for ongoing projects



Wind energy – continuing to gain momentum

Over 50 percent more electricity was generated from wind energy in 2015 than in the previous year. According to initial forecasts made by the IWR (the International Economic Forum for Renewable Energies), a total of 86.8 gigawatt hours of electricity was fed into the grid. By way of comparison: this figure reached just 57.4 gigawatt hours in 2014. Research funding from the BMWi in the area of wind energy supports this expansion with targeted funding measures to make turbines more efficient and reliable and to reduce costs. The aim is to replace smaller turbines with more powerful ones and thus contribute to reducing installation costs. In order to develop ever larger wind turbines, which are at the same time more robust, efficient and durable, it is necessary to test the components comprehensively. At the nacelle testing laboratory DyNaLab operated by the Fraunhofer Institute for Wind Energy and Energy System Technology IWES in Bremerhaven, complete nacelles with a power output of up to 8 megawatts have been tested since autumn 2015. Whether lightning strikes, short-circuits or gale-force winds: All adverse conditions that wind turbines are exposed to in nature can be simulated at this globally unique testing facility. The BMWi funded this project with around 19 million euros. In the area of wind energy, the BMWi approved funding for a total of 103 new research projects with a funding volume of around 85.4 million euros in 2015 (previous year: 63 projects with around 38.5 million euros). Ongoing projects received around 53 million euros in 2015.

The solar sector basks in new world records

Electricity from the sun's energy can be generated using two fundamentally different methods: Photovoltaics utilise the physical characteristics of semiconductors to generate electricity; solar thermal power plants in contrast, use the heat generated by the sun's rays to drive the power plant process. The BMWi funds research projects for both technologies.

The German market continued to be difficult for the photovoltaic industry in 2015. In contrast, global photovoltaic business developed positively – the German plant industry achieved a global market share of 50 percent in the first nine months of the year. This positive development is set to continue. The BMWi is contributing to this development with its research funding, with the aim of further reducing the cost of generating electricity from photovoltaics. One method to achieve this is to secure a higher yield through higher levels of efficiency. Successful examples of innovative and high yield solar cell concepts are the newly developed PERC technology and TOPCon solar cells. These two technologies enabled Germany to set new efficiency world records in 2015.

In the area of solar thermal power plants, Germany also primarily focuses on the export market. Solar thermal power plants require a climate with high direct irradiance as found in Southern Europe, North Africa or the USA. Research funding aims to help reduce the cost of this technology in order to make it competitive with other renew-

able energies such as photovoltaics. Larger mirrors in parabolic trough power plants could generate greater yields with lower production costs. Higher operating temperatures achieved through the use of new heat transfer media or innovative storage technologies also reduce costs. In principal, solar thermal power plants have the advantage of offering electricity on demand using heat storage systems that are cheaper in comparison to electrical storage systems.

In the area of solar research, a total of around 69.8 million euros of funding was awarded in 2015 (photovoltaics: around 59.7 million euros, solar thermal power plants: around 10.1 million euros). The BMWi funded 97 new photovoltaic projects and 16 new solar thermal power plant projects this year with a total funding volume of around 82.5 million euros.

The stable and reliable component of the energy mix: geothermal energy

The potential offered by deep geothermal energy will be further exploited in the next few years. This technology utilises the high underground temperatures found at depths of more than 1000 metres for heating or to generate electricity. In particular, the BMWi funds projects that contribute to making geothermal energy more economical despite the fact that each individual plant must be designed individually. The regional conditions, such as the composition of the thermal water or the geological structures, differ at each location. Amongst other projects, the GRAME research project run by Stadtwerke München was started in 2015 and has received funding of around 4.6 million euros from the BMWi. The aim of GRAME is to provide the entire district heating for Munich from renewable energies by 2040, with the majority being sourced from geothermal energy. Munich has the ideal geological conditions for this purpose.

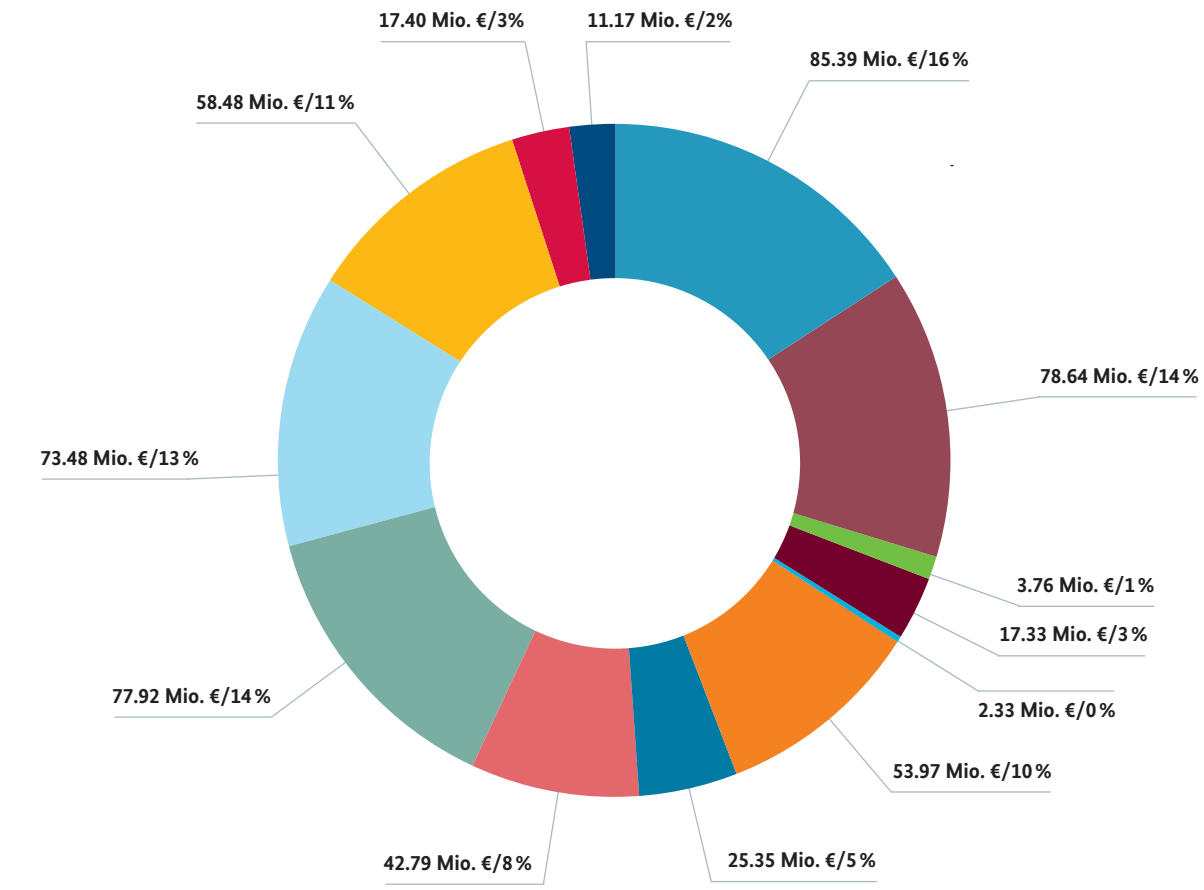
The heating transition – energy efficient buildings, districts and industrial operations

Almost 40 percent of primary energy consumption is accounted for by private households, offices, swimming baths, schools or other buildings. Buildings and districts require energy for heating and cooling, as well as for hot water and lighting. In view of the energy policy goals of the German Federal Government, there is great potential for savings in this area. This was the focus, for example, of the HeizSolar research project. In cooperation with its partners, the Fraunhofer Institute for Solar Energy Systems ISE is analysing different designs and utilisation concepts for the almost zero energy standard house “Solaraktiv” as part of the “Grid-Reactive Buildings” research project. Optimal designs are identified with the help of simulation models and measurement data.

Alongside simply funding projects, the “Energy in buildings and districts” research network founded in October 2014 has proved itself to be an important interface between research, business, politics and practice. The members of the network met in the spring of 2015 at their 1st Annual Conference in Berlin. They discussed the future need for research and development, which will be tackled, for example, by the planned “Solar Building & Energy-Efficient City” funding initiative. In 2015, around 51.2 million euros of funding was spent on new research projects in the area of energy efficient buildings and districts. This positive development was also reflected in the total approved funding volume for new research projects. It increased from around 47.2 million euros in 2014 to around 73.5 million euros in 2015.

Around 45 percent of electricity flows into industrial and commercial enterprise in the industrial location of Germany, which opens up opportunities for increasing efficiency in many areas. It is also possible to reduce primary energy consumption in many industrial processes. One possibility is the better utilisation of waste industrial heat. If this heat is made available, for example, for manufacturing processes or for internal company or public infrastructures, improvements in energy efficiency can deliver operational and economic advantages and at the same time reduce CO_2 emissions. In this area, the BMWi funds technologies for utilising waste heat, such as the development of so-called thermoelectric modules that can generate electricity from waste industrial heat. The “Abwärmeatlas” (Waste heat atlas) project is helping more precise forecasts to be made about the potential offered by waste heat in the industrial sector. In 2015, the BMWi approved funding for a total of 115 new projects with a funding volume of around 58.5 million euros.

Volume of funding for newly approved projects in 2015



The energy system of the future: Flexibility in the feed-in, storage and distribution of electricity

Electricity and heat generated from the wind or sun are dependent on the strength of the wind or the level of solar radiation. Flexibility is required, especially in the feed-in, storage and distribution of the generated energy. The BMWi supports research projects that create the required technical and system-related conditions. The most important issues include questions such as how can the electricity grids at all voltage levels be converted and expanded in order to, for example, transport electricity generated from wind energy in Northern Germany for use in Southern Germany. The various storage technologies for heat and electricity also need to be developed further. The BMWi has thus funded the development of the world's largest electrolysis plant – Energiepark Mainz – which has been using surplus electricity from wind turbines for the production of hydrogen that is then fed into the gas grid since the summer of 2015. Overall, the BMWi approved around 120.7 million euros of funding for new research projects in the area of grids and storage systems in 2015.

In order to exploit synergies and define funding themes, the German Federal Government has created a number of different initiatives. The "Energy Storage Funding Initiative", jointly supported by the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research (BMBF), has grouped more than 280 research

projects together under this theme. What contribution can energy storage make to the energy transition? How can they be profitably implemented? And what should be the focus of future research? These questions were the focus of the 2nd status seminar of the Energy Storage Funding Initiative in April 2015 in Berlin. The "Future-proof power grids" research initiative was created more recently. The BMWi and BMBF fund more than 300 projects through this initiative that are working on solutions for intelligent distribution grids, transmission grids, grid planning and grid management. In addition, the "Power grids" research network was founded in May 2015 as a platform for discussion and the exchange of ideas between experts from the worlds of industry and research on the subject of electricity grids. Expertise and innovative ideas are brought together here with productive and beneficial results.

Simulating and modelling the energy system of the future

Supplying energy to the Federal Republic of Germany has become more complex due to the energy transition. Therefore, models and simulation programmes are important tools for the energy industry. This is where systems analysis is applied: The resulting models, simulations and predictions help, amongst other things, to assess the development of planned short, medium and also long-term energy policy measures. In order to promote an exchange of ideas about new developments in this area, the Energy Systems Analysis research network was founded in March 2015 on the initiative of the BMWi. The first annual conference for this network was already held in Berlin at the beginning of December 2015.

Source of hope: Fuel cell technology

Fuel cells used in combination with hydrogen technology fulfil the goals of the energy transition in two respects. A fuel cell is a very efficient converter of energy for generating electricity and thus contributes to the reduction of primary energy consumption. Hydrogen, which can for example in combination with a fuel cell provide fuel in the mobility sector, is an ideal storage medium for renewable energies. In this area, the BMWi funds components of cells through to entire systems which, depending on their application, convert electrical energy into hydrogen or vice versa.

The latter, the electrolysis, is considered a promising technology for storing regenerative electricity. The German Federal Government has bundled related research and development activities under the "National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP)". At the full meeting of NIP in the summer of 2015, the first conclusions from the successful ten-year programme were drawn and the continuation of the measures was announced.

New challenges for conventional power plant technology

Although the contribution made by conventional energy sources to the German energy system is declining, gas, steam and coal power plants are still required for maintaining the security of supply and grid stability. The main focus of research funding is placed on those research projects that are working to increase the flexibility, efficiency and profitability of power plant processes and that utilise new materials and develop material technologies for this purpose. In addition, the Ministry supports projects focussing on CCS technologies and other measures for reducing emissions. Overall, a total of 108 new projects with a funding volume of around 54 million euros were approved in 2015.

The restructuring of the energy system is on schedule

A review of the developments and activities in the energy sector in 2015 demonstrates that the energy transition is well on track to deliver a safe, environmentally friendly and economically successful future. Constant research and systematic technological advancements are indispensable to this process. The strategic and application-oriented research funding from the BMWi makes a decisive contribution to the restructuring of the entire energy system and to the retention of Germany's position as a technological leader.

Wind energy

The use of onshore wind energy is a central component of the energy transition because it is currently the least expensive technology for generating electricity from renewable energies. It currently also makes the largest contribution to electricity generated from renewable energies in Germany. There is great potential for the further expansion of wind energy both through the increased utilisation of the wind at sea and also by opening up suitable onshore locations using modern, more efficient turbines.

Market developments in Germany and across the world

According to information provided by the transmission system operators, the highest value for feed-ins from wind turbines in Germany in 2015 was around 32.5 gigawatts – this figure was achieved on 21 December between 9:30 pm and 9:45 pm. In the previous year, the peak value for electricity fed into the system stood at only 29.7 gigawatts, which was also measured in December. The enormous expansion in wind energy is demonstrated even more clearly by the volume of electricity fed into the system during the whole of 2015. According to data from the IWR (the International Economic Forum for Renewable Energies), a total of 86.8 terawatt hours was achieved during this particularly windy year. The figure in 2014 was just 57.4 terawatt hours – meaning that the volume of electricity had increased by more than 50 percent. These new record values underline the great importance of wind energy for the achievement of the energy transition in Germany. The IWR forecasts more than 100 terawatt hours in 2016. This means that more electricity will be generated from wind energy than from nuclear power plants for the first time.

In particular, it is important to highlight the expansion of offshore wind energy in 2015. While the one gigawatt mark for installed output was just exceeded for the first time at the end of 2014, output has already more than tripled during the course of 2015 according to the German wind farm operators. 546 offshore wind turbines across nine different offshore wind farms were added to the grid and the connected offshore capacity increased by around 2.3 gigawatts. Overall, 792 offshore wind turbines with a total output of around 3.3 gigawatts were connected to the grid as of 31 December 2015.

There is thus not far to go to reach the offshore expansion goals set by the German Federal Government of 6.5 gigawatts of installed output by 2020. There are already further wind turbines with an output of around 200 megawatts installed that just need to be connected to the electricity grid. In addition, wind turbines with an output of around 1,000 megawatts are already under construction and the investment decisions have already been made regarding wind turbines with a total output of around 900 megawatts.

The expansion of onshore wind has progressed equally well. According to data from the German wind farm operators, a total of 1,368 new wind turbines were erected onshore in 2015 with a total output of around 3.7 gigawatts. This figure also includes repowering turbines: new and generally larger wind turbines that replace old ones in order to increase the yield for that location. 253 wind turbines were dismantled in total and not all were replaced, resulting in a net expansion of around 3.5 gigawatts. As of 13 December 2015, a total of 25,982 onshore wind turbines with an output of around 41.7 gigawatts were in operation.

The trend towards larger turbine outputs and also longer rotor blades is continuing. Due to the achievement of a higher number of full load hours, the feed-ins have stabilised to a significant degree and fluctuations in the supply of electricity from wind energy have been reduced. In addition, sites where the wind is not as strong can also be connected, significantly reducing the need for grid expansion.

The global market has recovered following its collapse in 2013. The driving force in this area continues to be Asia, led by China. The newly installed output worldwide was around 46.3 gigawatts over the whole of 2015. Other promising markets are Chile, Brazil, Mexico and India.

Progress in research and development

Onshore wind energy is already comparatively well developed. Its technical availability is over 95 percent. In order to push forward the expansion in a cost efficient way and to strengthen the energy supply using renewable energies, the focus continues to be placed on larger rotor blade diameters. On the one hand, they enable a higher number of full load hours, which makes it easier to predict and plan electricity production, while on the other hand, these so-called “weak wind turbines” can also be used in locations with less favourable wind conditions. There appears to be a general trend for these types of wind turbines, which is being followed by a number of companies. The research and development activities in this area are thus being carried out more intensively (also see “Quicker and more efficient testing of rotor blades”, page 20). A challenge to the development of larger rotor blade diameters is their effect on the gearbox and bearings. The **HAPT** project, for example, focuses on rotor blade bearings and the problems faced by this weak point (also see “New test stand for blade bearings”, page 22).

A further development trend is the modularisation of wind turbines. There are also a number of companies offering corresponding products in this area. Due to the increasing dimensions of the turbines, it is important to be able to transport them cost-effectively. Special transport always results in high logistical costs – especially for the approval of the transport itself. This can be avoided by the use of modular components that are only connected together at the intended location.

The new regulation for the needs-based lighting of wind turbines that has been valid since the middle of 2015 can also be considered a research and development success story. It is thus permitted to switch off lighting designed to identify the wind turbines at night. The lighting must only be activated if an aircraft approaches the turbine. As this reduces the disturbance to local residents around wind farms, it makes a more socially acceptable expansion of onshore wind possible (also see “In Focus”, page 14).

The expected lifespan for many new onshore wind turbines has been increased from 20 years to between 25 and 30 years. Despite the higher production costs, the new and more powerful turbines generate cheaper electricity over their entire lifespan than earlier models.

Furthermore, different large-scale test stands now exist that can be used to quickly and reliably test newly developed components and machinery. For example, the **DyNaLab** was opened in 2015 (also see Highlight Project, page 24). This testing laboratory operated by the Fraunhofer Institute for Wind Energy and Energy System Technology IWES in Bremerhaven enables complete nacelles with a power output of up to 8 megawatts to be realistically tested under laboratory conditions. This testing environment is unique the world over. Pilot customers include the companies Jacobs PowerTec, ECO5 and Adwen.

IN FOCUS

The residents in the vicinity of wind farms have on average a positive attitude

Acceptance for the further expansion of renewable energies is an important component for a successful energy transition. In public discussion, there is often the impression that there is a poor level of acceptance for wind energy. The team headed by Professor Gundula Hübner at the Martin Luther Universität Halle-Wittenberg has ascertained during a total of four large-scale psychological studies on the environment since 1999 that acceptance amongst the majority of the population is high – it is the minority that is driving the debate. Gundula Hübner summarised some of the key results in an interview for the BMWi Annual Report on Research Funding.

Professor Hübner, what does "acceptance of wind energy" mean to you?
Hübner: My team and I define acceptance as a neutral or positive attitude to a project. We also consider actual behaviour. Attitudes are – more or less good – predictors of behaviour.

What have you found out about the attitudes of the population up to now?
Hübner: We investigate the acceptance amongst residents in the vicinity of already built wind turbines. Our random samples demonstrate that these people have on average a positive attitude. However, it is important to make a distinction to the situation when a project is being planned. The level of uncertainty is greater, which is why lower acceptance levels are found to some extent. I say „to some extent" because the resistance shown by minorities during public discussions is emphasised a great deal more than the positive attitude of the majority. Interesting projects and important work is currently being carried out in this regard, such as in the "Dezent Zivil" project.

When is acceptance high?
Hübner: First of all: Acceptance is generally relatively high. It is then even higher if people know that the majority are in favour of a project. Specifically at a local level, it is also important for people to understand the reasoning behind the project. This means who benefits from the project – the local authorities? The individual residents? Is it a project that actually contributes to the energy transition and is necessary? In the case of wind turbines, it is also important that residents are taken into consideration on an equal footing. Any creative freedom available within the project should also be exploited as far as possible together with residents.

What still needs to be taken into account in the expansion of wind energy?
Hübner: An important aspect for acceptance is that people need to be sure that this expansion really has no negative consequences. Especially when it comes to noise, there are some people who are severely affected. According to our definitions, these people experience at least one symptom that they themselves associate with the wind turbine, such as problems sleeping or the avoidance of certain areas. In order to ensure that there is no uncertainty, it is necessary to look more closely at what noise the turbines actually make. I do not mean the amount or volume of noise here but rather the quality of the noise. This low and gentle whooshing sound generated by wind turbines is a so-called stress trigger. We are all familiar with the impact of this type of noise: You are walking through the forest on a warm evening – and suddenly you hear a small crack of a twig breaking somewhere. You are immediately fully alert. Those people who have a keen sense of awareness can hear the quiet whooshing sound, maybe while they are falling asleep and then have adrenaline pumping through their veins. The quality of the noise is dependent on the design of the wind turbines. It is thus important to include the impact of the turbines on people to a greater extent during the development, for example, of

Prof. Gundula Hübner,
Martin-Luther-Universität Halle-Wittenberg

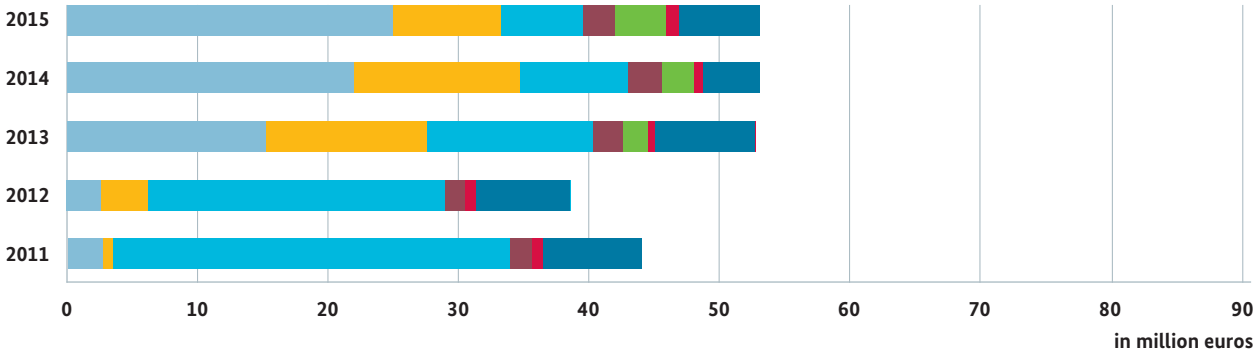
the rotor blade profiles – a kind of "Homo Sapiens Monitoring". Bringing technology and psychology closer together here would seem to be an important aspect.

What technological improvements have been achieved since you completed your first study in 1999 that have led to higher levels of acceptance?
Hübner: One improvement is certainly the shadow casting regulation. This regulation is based on the psychological study from 1999. It was clear that there was a significant disturbance being caused and legislators responded by defining the length of time a shadow is allowed to be cast in order to protect people – engineers then developed the shadow casting model on this basis. The so-called disco effect has also been resolved because the coat of paint has been changed. The lighting at night that demarks an obstruction can also be switched on and off as required since 2015. There has also been a lot of progress with noise, which has been tackled by the emissions protection directive. However, there has still not been enough examination of the quality of the noise. The monetary and non-monetary participation options have improved but still need to be investigated and improved further.

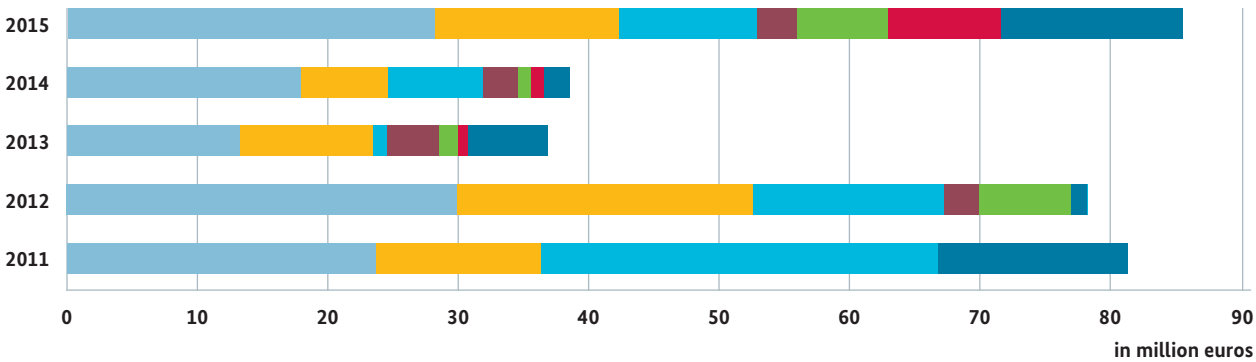
Wind turbines near to residential areas need to be designed to minimise noise

In the area of offshore wind, research and development has delivered suitable noise protection measures that can be used during the installation of foundations at water depths of up to 40 metres. In general, the piles for the turbines are rammed into the ground which causes corresponding noise under the water. However, the prescribed noise emission limits can now be met using a variety of technological approaches. One example is the "Big Bubble Curtain" – a curtain of bubbles around the construction location – that insulates the noise when the pile is being rammed. Because the innovative technologies reduce the range of disturbances for marine mammals by up to 90 percent, they make a significant contribution to the protection of species in the German exclusive economic zone. However, the measures that have reached market maturity are additional measures that only reduce the propagation of the noise. As these measures always result in additional costs, other concepts are currently being developed that mean less noise is produced. One solution that is particularly worth mentioning are suction buckets or suction bucket foundations. This new type of foundation is sucked into the ground rather than being rammed, producing only low levels of noise.

Wind energy: Distribution of funding between 2011 and 2015



Trend in the volume of newly approved funding since 2011



- Facility development
- Offshore
- Logistics, installation of wind turbines, maintenance and operation
- Environmental aspects of wind energy and ecological research
- Wind physics and meteorology
- Onshore
- Other

Strategy for the research funding

Wind turbines continue to have the potential to make the largest and most economical contribution to increasing the proportion of electricity production accounted for by renewable energies. The research funding from the Federal Ministry for Economic Affairs and Energy (BMWi) in the area of wind energy should thus contribute, in particular, to generating this electricity even less expensively. It is important to increase the yield from the turbines and to guarantee reliable operation – both of which are important aspects for reducing specific costs.

However, questions about how to cut down on materials and further increase the output from individual turbines are increasingly becoming the focus of research. This conserves resources and saves on installation costs – and makes it possible for fewer larger turbines to deliver the same performance as lots of smaller turbines.

Another issue relevant to the further expansion of wind energy is the ability to better predict and consolidate the electricity generated from wind energy. This requires, for example, a deeper understanding of wind as a resource in order to utilise it as efficiently as possible. Research methods include improving forecasts for wind yields in difficult terrains such as (low) mountain ranges or forested regions. Another approach is to optimise methods for simulating wind loads in order to design turbines accordingly. Research is also being carried out into new control concepts for wind turbines and wind farms to optimise the energy yield (also see “Controlling the wind”, page 23). Using intelligent, predictive status and load monitoring systems, it should also be possible in this context to avoid extreme loads and any resulting damage (also see “Sensors provide valuable insight”, page 20).

There are plans to establish an onshore test field called the “German Research Facility for Wind Energy” to determine the optimal design for onshore wind turbines. This research facility should also test unfavourable wind conditions using high quality measurement instruments – for example when all turbines are located in front of one another in the direction of the wind. It will also enable field tests to be conducted on newly developed turbine components without the need to erect the complete prototype for the wind turbine.

The integration of the generated electricity into the public supply grid is another research topic. Alongside improvements in wind forecasting as already mentioned above, the research focuses on issues relating to the connection of offshore wind farms to the grid, load and generation management and aspects of storage that relate specifically to wind energy.

The theme of acceptance is particularly relevant in the onshore sector (also see “In Focus”, page 18) in order to be able to continue to implement the expansion of wind energy as planned. An issue specific to the offshore sector, in contrast, is the need to make further significant cost savings in the areas of installation, logistics, operation and maintenance (also see Highlight project, page 21). The wind turbines installed on the high seas can only be reached with a considerable amount of effort and during a limited time frame – suitable software solutions that deliver optimised deployment plans are thus one solution for maintaining cost efficient and low risk operation.

In the area of wind energy, the BMWi approved new funding for a total of 103 projects with a funding volume of around 85.4 million euros in 2015 and thus significantly increased the level of funding in this area (2014: 63 projects with around 38.5 million euros of funding). Ongoing research projects were provided with approximately the same high level of funding as in the previous year with around 53 million euros (2014: around 53.1 million euros).

IN FOCUS

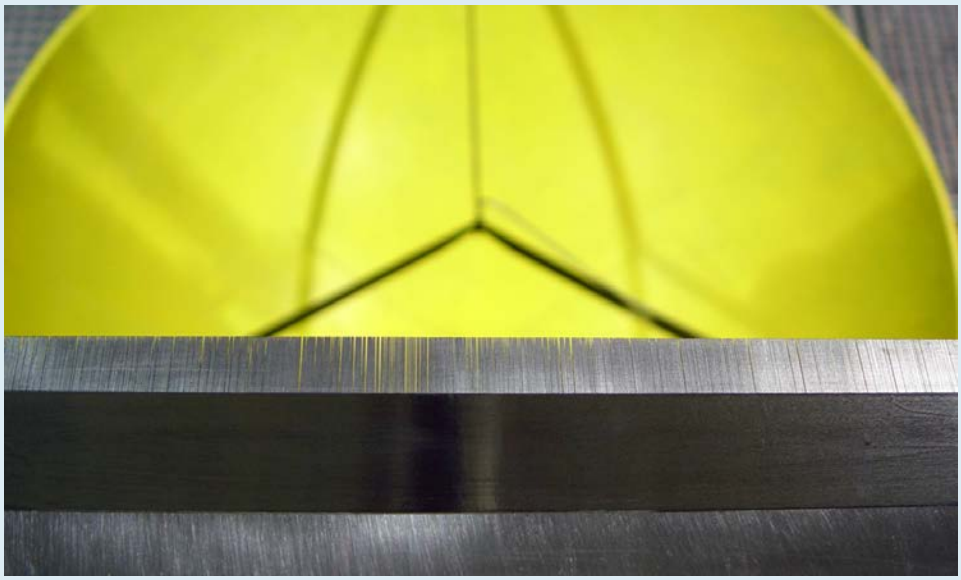
Quiet please!

The noise generated by a wind turbine is a decisive criterion for its economic efficiency that is as equally relevant as its output. Noise emissions are being integrated into the approval process in order to define the clearance required to the closest housing developments – to ensure that the turbines do not disturb residents. If a turbine delivering a nominal output is too loud and is thus not permitted to be erected it is no use to anyone. In order to continue the expansion of wind energy, a variety of research projects are working on making the rotation of the rotor blades and the operation of the drive train as quiet as possible.

If it is possible, for example, to reduce the noise level of individual wind turbines by one, two or three decibels then it may be possible to increase the total number of wind turbines. The potential output of the wind farm could then be increased by up to 100 percent with the same noise emissions.

The individual German states currently define the permitted noise levels in their state building regulations. The established regulations are based on rules of thumb. An approval process is initiated for every new turbine and every repowering turbine and tests are carried out in each individual case.

The main causes of the noise lie in the boundary layer of a rotor blade. This is a thin layer of air that directly surrounds the rotor blade. The movement of the rotor blade causes turbulent pressure fluctuations in the boundary layer. This turbulence propagates to the trailing edge of the rotor blade and is emitted here as sound into the local environment. As the turbulence is directed towards the trailing edge of the blade, the profile of the blade has a major influence on the resulting noise levels. In



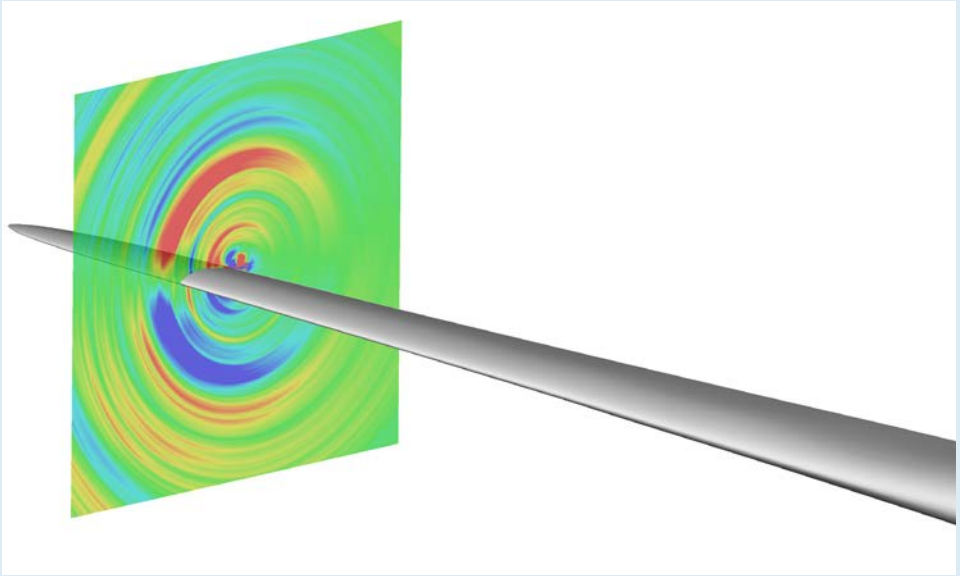
Brush appendages on the trailing edge of a rotor blade reduce the development of noise

general, the noise level also rises as the speed of the rotor increases and the diameter of the rotor blade increases – these two aspects have a direct influence, however, on the yield of the turbine, which is why many research projects on the subject of quiet rotor blades focus on the blade profile. The aim is to reduce the air turbulence within the boundary layer as effectively as possible so that the sound is not even emitted.

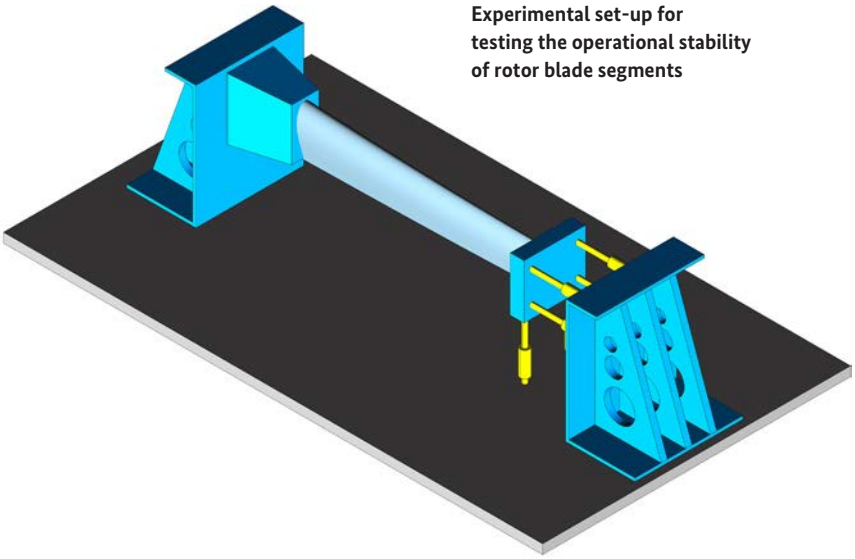
In order to reduce noise, it is possible to use passive and also active measures. Active measures require energy but can be adapted to match the exact wind speed conditions. For example, targeted suction across the surface of the boundary layer has been proven to reduce noise emissions. Scientists working on the German-Israeli project **ActiQuiet**, with participation on the German side from the Institute of Aerodynamics and Gas Dynamics (IAG) at the University of Stuttgart, have achieved significant noise reductions of up to 6 decibels with moderate suction levels.

Passive measures often start with the form of the blade profile. A corresponding project was already completed by GE Wind Energy in 2010. Using trailing edges with a saw tooth design or trailing edges made out of porous materials, it was possible to significantly reduce noise levels. The current **BELARWEA** project of the German Aerospace Center (DLR) focuses on the design of the blade tips. Amongst other things, the aim is to utilise noise reduction technologies from the aerospace industry such as brush appendages.

The newly launched project **RENEW**, which is coordinated by Senvion, ultimately includes both passive and active concepts. The project is developing one of the quietest – and longest – rotor blades for high-yield onshore wind turbines in low wind sites. Close scientific collaboration exists here with the University of Siegen. Through the measures being investigated, on the one hand, inhibit the development of the noise should be inhibited by manipulating the turbulent boundary layer and, on the other hand, disperse the noise waves that do develop on the trailing edge of the rotor blades in a beneficial way. The aim is ultimately to transfer these solutions from a laboratory model to real turbines.



A simulation evaluates how much noise is being generated by the rotor blade



Experimental set-up for testing the operational stability of rotor blade segments

Selected funded projects

Quicker and more efficient testing of rotor blades

The rotors on wind turbines are becoming ever larger and the rotor blade more flexible. This presents new challenges for testing the operational stability of the blades. In the project **Future concept for the operational stability of rotor blades**, the Fraunhofer Institute for Wind Energy and Energy System Technology IWES in Bremerhaven is developing new methods for testing blade segments, blade sections and components. The testing times and costs can thus be reduced and the modelling of the operating loads improved.

The researchers want to reduce the testing times for rotor blades by carrying out tests on segments of the long blades – instead of testing the whole blade as previously. Thanks to the newly developed segment testing, it should be possible to reduce the overall duration of the tests and thus the energy required by up to 30 percent. In addition, the scientists want to utilise the component and blade section tests to develop better options for validating the material models used. Furthermore, individual rotor blade sections can be subjected to more in-depth or follow-up testing without the need for entire rotor blades to be produced for this purpose. These possibilities could be used, for example, for design modifications or new rotor blade designs so that verifying the operational stability can be simplified using innovative approaches. One example are so-called smart blades that are utilised to reduce the load placed on the whole turbine. The project is being funded by the BMWi and the State of Bremen. The proportion funded by the BMWi was around 2.5 million euros.

Sensors provide valuable insight

The power transmission elements in wind turbines are exposed to highly dynamic stresses. Any imbalance or vibration generated during the operation of the wind rotor triggers additional forces and moments in the drive shafts. This can lead to bearing or gearbox damage and cause l ong downtimes for the turbines. However, meaningful measurement data is lacking for making targeted progress in the areas of design, production and selection of materials.

In the joint project **BiSWind**, coordinated by Schaeffler Technologies, the aim is to develop integrated sensors for the power transmission elements in wind turbines. The individual gearbox components such as the shafts, bearings or gear wheels have only been accessible to measurement technology to a limited extent up to now. Therefore, the researchers aim to develop an autonomous measurement system for condition monitoring that is based on integrated sensors. Above all, the aim is to monitor the torque but also the temperature of components, vibration and the speed. The system needs to be resistant to ageing and media such as coolants, lubricants or moisture – especially in the case of offshore application – in order for the technology to be successfully transferred to mass production. The project partners are thus investigating technologies and concepts for directly integrating the sensors and strip conductors onto the surface of the components without using adhesive bonding. They aim to achieve this by using thin film technology and microstructure techniques.

The new sensors will enable targeted maintenance strategies to be developed and will thus increase the technical availability and reliability of wind turbines. The load conditions in the drive train can be reliably recorded and can act as the basis for the development of innovative control and management concepts. This is decisive for the economic operation of wind turbines especially in exposed

HIGHLIGHT

Flexible ships enable efficient installation

The wind is blowing strongly and the waves riding high. Installing wind turbines on the high seas in these types of weather conditions is unthinkable. The installation ships have to remain in port on days such as these and simply wait for better weather conditions. Yet this increases the installation costs for a wind farm. Therefore, Senvion is developing a new installation and logistics concept including innovative transport and lifting concepts for wind turbine components in the "Skills" research project together with the LogDynamics research cluster at the University of Bremen and Deugro Denmark as an associated partner.

Installation ships that have been used up to now, so-called jack-up barges, are self-elevating with extendible legs. This enables them to lift and install the large components of a wind turbine that often weigh many hundreds of tons at sea. Usually, all of the components are transported from the port of loading to the installation site on the installation ship itself. As the ship needs to commute between the port and the installation site a number of times to transport all of the components, the actual on-site installation time often only accounts for 75 percent of the time for the entire logistics. As offshore wind energy is expanded, areas further and further out to sea are being connected and thus the transport times are also increasing. Depending on its size, this type of installation ship costs around 150,000 euros per day to hire – irrespective of whether the ship is installing the turbines, transporting the components or waiting in port due to poor weather.

This is where the **Skills** project comes in. The aim of the concept is to transport the components using cheaper transport ships. The researchers thus aim to significantly increase the efficiency of the employment of the installation ships and reduce costs. The project partners plan to use so-called feeder ships, which supply wind turbine components to the installation ship. The installation ship itself can in turn remain on-site in the wind farm. The feeder ships can be flexibly designed and also serve as mobile temporary storage for the components. The concept has been designed for the installation of six megawatt turbines under North Sea conditions and can be utilised for wave heights up to 2 metres.

Yet in order to practically implement the task, the project partners still need to resolve some challenges: For example, lifting the large, complex wind turbine components weighing many tons from the unsteady transport ship to the stationary platform on an installation ship is currently not possible even in only slightly unfavourable weather conditions. Components could be damaged and people would also be placed in danger. The scientists working on the Skills project are thus also developing innovative lifting concepts and new technological solutions for transporting the components, as well as a way to dampen the movements of the components. This new lifting and transport concept is due to be demonstrated in the Nordsee One offshore wind farm operated by RWE. The BMWi is funding this project with around 3.1 million euros.

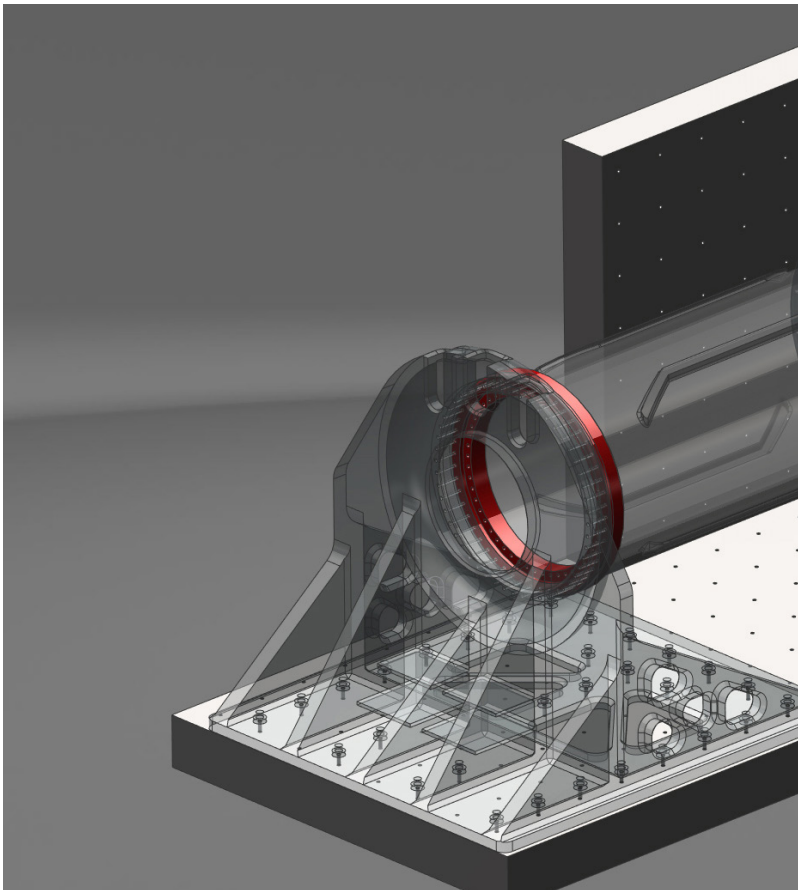
A jacked up installation ship (centre of picture) with a feeder ship carrying components (right). A turbine will be installed from here onto the monopile (left)

and difficult to access locations such as those situated offshore or in mountainous regions. Alongside Schaeffler, seven other partners from the areas of industry and research are participating in the project. The BMWi is funding this project with around 2.4 million euros.

Wind energy research facility at the University of Bremen

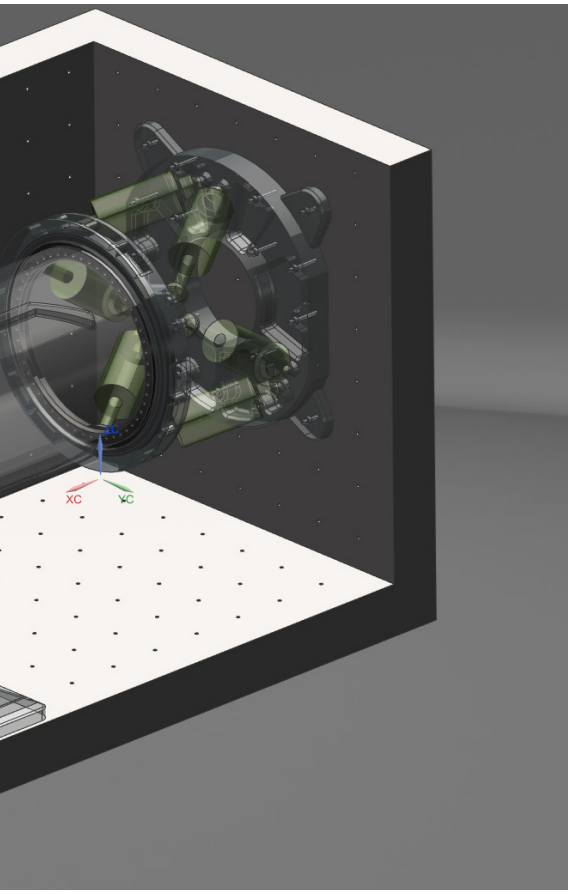
New test stand for blade bearings

The blade bearings used in wind turbines that enable the rotation of the rotor blades along their longitudinal axis and thus the setting of the angle of the blade are currently largely selected based on experience. However, wind turbine manufacturers aim to make important changes to the control of their turbines in the future that include, amongst other things, the continuous and individual adaptation of the pitch of the rotor blades (individual pitch control, IPC). As a result of these measures to reduce the loads, the structure of a wind turbine can be made lighter and thus less expensive – which reduces the cost of electricity from wind energy. IPC balances the loads placed on the individual rotor blades and thus reduces the overall load placed on the structure of the wind turbine. However, it is currently not possible to make reliable statements about the suitability of rotor blade bearings to implement this measure. Furthermore, IPC also increases the demands placed on the bearings. The increasing size of modern wind turbines places greater requirements on the load-bearing capacities of the bearings.



In the **HAPT** (short for Highly Accelerated Pitch Bearing Test) project, the aim is thus to construct a test stand for the accelerated fatigue testing of blade bearings and to develop a corresponding accelerated testing method. The required blade bearing can thus be designed through calculations and the results validated each time under realistic conditions. New bearing concepts and control algorithms can then be developed using these values.

Based on the completed fatigue tests, the dimensions of the bearings can be precisely defined for the requirements of IPC. In addition, the scientists are developing a method for calculating the lifespan of the blade bearings based on the test results. The Fraunhofer Institute for Wind Energy and Energy System Technology IWES in Bremerhaven is coordinating the project, in which the IMO Group and the Leibniz Universität Hanover are also participating. The BMWi is funding HAPT with around 10.7 million euros.



Planned HAPT testing set-up with 4-metre test bearings (red)

Controlling the wind

Wind turbines are becoming increasingly larger and more complex. As offshore wind energy is expanded, the loads placed on the wind turbines are also increasing due to the adverse environmental conditions. This places new demands on the control technology because this is what keeps a turbine stable in its optimal operating range. In the **Wind under Control** research project, the scientists at the Fraunhofer Institute for Wind Energy and Energy System Technology IWES in Bremerhaven are working on the further development of current control systems. By using improved dynamic models and advanced control algorithms, modern multi-megawatt wind turbines can be operated efficiently and economically.

The models currently used to develop control systems have fallen behind the rapid development of wind turbines. For example, they do not sufficiently take into account the flexibility of the rotor blades and the tower or the interaction of the components. In parallel to the growth in size of turbines, the vibrations due to the flexibility of the system components are also increasing. Therefore, it is increasingly important to take into account the vibration dynamics of the wind turbines. Consequently, both the effect of the control system on the loads experienced by the components and the design of the control system itself need to be developed further in order to reliably reduce the loads.

The scientists aim to develop dynamic models for control technology on the basis of these new requirements and use them as a software module for a real-time simulator. On the basis of these models, it should be possible to derive control algorithms and test them on a reference turbine. Ultimately, the researchers want to test the optimised control system on the nacelle test stand at DyNaLab (Dynamic Nacelle Testing Laboratory) (see page 24). The BMWi is funding Wind under Control with around 1.6 million euros.

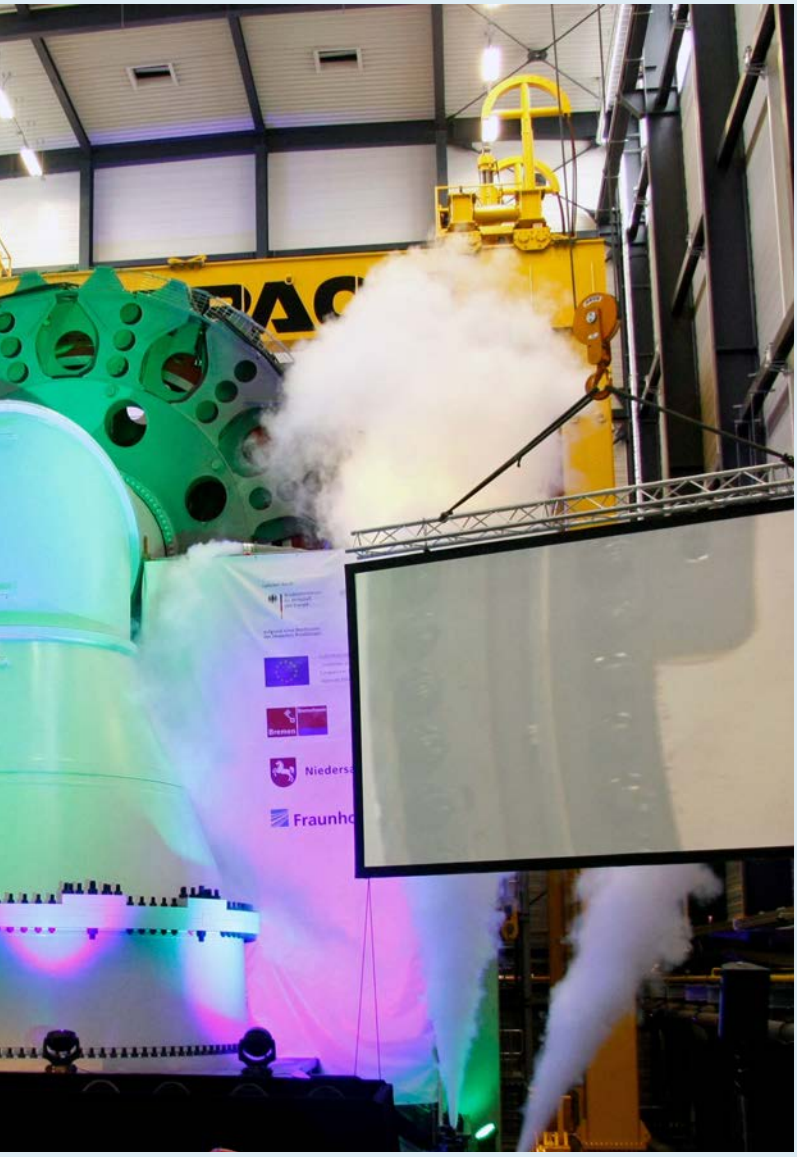
HIGHLIGHT

Test stand for complete nacelles placed into operation

A globally unique testing facility was placed into operation in the autumn of 2015 in the form of the nacelle test stand at the Fraunhofer Institute for Wind Energy and Energy System Technology IWES. Complete nacelles – the equipment housing at the top of wind turbines – with an output of up to 8 megawatts can be realistically tested here under laboratory conditions. "Finally: Never again having to wait for the wind and never again having to ask the grid operator", is how Professor Jan Wenske from the Fraunhofer IWES summarised the advantages offered by the test stand in his opening speech. The development of wind turbines will be greatly accelerated as a result. New, powerful and, above all, reliable systems will be brought to the market more quickly which will thus contribute to a successful energy transition.

The nacelle test stand is the centrepiece of the newly established Dynamic Nacelle Testing Laboratory, in short **DyNaLab**. Alongside the central test stand, another test stand – also funded by the BMWi – for investigating the operational stability of the main shafts of wind turbines is currently being placed into operation. In addition, there are plans for other smaller test facilities for important individual components such as converters, generators or anti-friction bearings. The nacelle test stand, which weights over 700 tonnes, is located in the central 30 metre high hall. The construction work was completed in just 18 months – from the laying of the foundation stone though to commissioning. "The components – which in some cases are unique – are sourced from across the whole of Europe," explains Jan Wenske. "This high-tech machine was created though painstakingly detailed work." A number of companies contributed to the building of it.

The nacelle on a wind turbine includes the drive train and generator, as well as other components such as brakes or the turbine's control elements that influence, amongst other things, the speed of the rotor. The nacelle is where the movement of the rotor generates electrical energy. This rotary motion and all loads caused by the wind flowing onto the rotor blades (which can currently be up to 80 metres long) are now artificially generated at DyNaLab by the new test stand. The nacelle being tested is docked onto the test stand and at the push of a button is subjected to all operating states that are theoretically possible – whether it is a storm, gusts of



DyNaLab's nacelle test stand at Fraunhofer IWES was placed into operation in October

wind or sudden periods of calm. A drive motor with an output of 10 megawatts simulates the torque of the rotor, while other forces such as pulling and pushing of the oscillating rotor blades in the wind are applied hydraulically.

The impact of the pitch system, which is used to adapt the angle of the rotor blade to the wind speed, or the yaw system, which turns the nacelle in the direction of the wind, are integrated into the tests.

A virtual medium voltage grid with up to 36,000 volts that is connected to the test subject supplements the mechanical tests – this virtual system fitted with 44 MVA (megavolt amperes) inverters is the most powerful simulated electricity grid in the world. As the condition of the electricity grid has a direct influence on the operation of a wind turbine, a variety of different grid states are reproduced. Possible questions include how the wind turbine behaves in the event of an emergency stop or in the case of a grid outage. In contrast to tests carried out using the real electricity grid, it is possible to reproduce the different states with a high level of repetition. Moreover, any possible deficiencies in the nacelle prototype do not have any influence on the regional energy supply.

The test stand is available to all turbine manufacturers and makes it possible to complete meaningful laboratory tests to evaluate and optimise existing and future system concepts. The infrastructure of the DyNaLab ensures that the test subjects can be quickly and flexibly changed. The BMWi funded this project with around 19 million euros. Overall, funding totalling 35 million euros has been received by the project (of which 6 million euros was awarded by the Federal Ministry of Education and Research (BMBF), 6 million euros by the State of Bremen (European Regional Development Fund) and 4 million euros from the Fraunhofer-Gesellschaft.

Solar energy

Electricity can be generated from solar energy using two fundamentally different methods. Photovoltaics utilise the physical properties of semiconductor materials. This technology is easy to use in Germany and an attractive offer for many homeowners due to the funding offered by the German Renewable Energy Act (EEG). Whereas in the case of solar thermal power plants, the heat from the sun's rays is captured in order to initiate a power plant process. This requires a climate with high direct irradiance as found in Southern Europe, North Africa or also parts of the USA. Therefore, solar thermal power plants are developed in Germany exclusively for export.

Market developments in Germany and across the world

Photovoltaics together with wind energy are said to mainly provide Germany's energy supply in the future. They accounted for 6 percent of German electricity consumption in 2015 and for 20 percent of the electricity generated from renewable energies.

The German market continued to be tough for the photovoltaic industry in 2015. The expansion amounted to approximately 1.5 gigawatts, falling short of the target of 2.4-2.6 gigawatts. In contrast, the global market increased further in 2015 and confirmed the positive trend that was already noticeable in 2014. According to analyses carried out by a number of consultancy companies, a total between 55 and 59 gigawatts of photovoltaic output was installed globally in 2015. This represents a clear increase in comparison to 2014 for which the figure was 42 gigawatts. The driving markets are China, Japan, and the USA, which alone account for around 60 percent of installations. Global growth also opens up good opportunities for German companies as they are able to provide high-quality products at competitive prices.

In Germany, three companies are currently active in the production of solar cells and modules for the mass market. One of these companies is the SolarWorld Group. Two new companies began manufacturing or expanded their production capacities for solar cells and modules in Germany in 2015 and thus added a further manufacturing capacity of around 500 megawatts.

The SolarWorld Group is currently switching its production to PERC technology as a direct consequence of its successful research and development activities (also see Interview, page 28). PERC cells (Passivated Emitter and Rear Cell) stand out due to their very good front and rear passivation. In contrast to the previously established Al-BSF cells (Aluminium-Back Surface Field), the rear of the cell only has local contacts instead of a full-area aluminium layer. Therefore PERC cells lower the electricity costs. The switch to PERC technology also appears to be a general trend internationally and is thus set to replace the previous AI-BSF cells.

German plant engineering in the area of photovoltaics experienced a clear upswing in 2015. With a global market share of over 50 percent, German mechanical engineering in the field of photovoltaics was able to also maintain its excellent competitive position in the first nine months of the year. However, the competition is becoming increasingly intense, especially with Asian suppliers. At the same time, the American market is gathering pace.

In the area of solar thermal power plants, international competition and also the global market, which has a relatively subdued growth overall, are a challenge. Power plants are being built across the world, but yet the number of new power plants has remained relatively low as costs have not been reduced significantly enough, particularly in comparison with photovoltaics (also see "In Focus", page 36). The low turnover generated by solar thermal power plants also meant that cost reductions through economies of scale by a larger number of products could not be realised. In January 2016, there was a total global power plant capacity of around 4.6 gigawatts, although this only represented growth of approximately 0.6 gigawatts compared to the previous year. The lower demand has now led to reduced production capacities in Germany.

It is essentially foreign companies that are supplying and planning projects for these power plants, especially those from Spain, Israel and the USA. However, Germany remains an important supplier of components such as heliostats, parabolic troughs and receiver tubes, as well as for the power plant section of the solar thermal power plant. In this part, German component manufacturers and suppliers hold a leading technological position. The relevant research institutions in this area include the Solar Institute Jülich (SIJ) at the FH Aachen and the German Aerospace Center (DLR) which operates, for example, the demonstration power plant in Jülich and will now be expanded to become a research site (see page 37).

Solar thermal power plants are expected to play a greater role in the future. In general, they offer two significant advantages compared to photovoltaics and wind energy: Due to the comparatively simple storage of heat, energy can be produced on demand. In addition, the power plants can be operated in hybrid mode – where the solar thermal power plant block is combined with a fossil fuel-fired block. This enables the gradual "solarisation" of the energy supply system. Solar thermal power plants thus hold a position of great importance in sun-rich countries for transforming electricity generation into a regenerative, climate-neutral system. In these regions, the technology itself offers the benefit of a local value chain: It creates jobs for the on-site construction and operation – in contrast to photovoltaic power plants where the finished photovoltaic modules need only to be installed.

Progress in research and development

In the area of photovoltaics, there are generally a variety of different solar cell technologies, some of which utilise a variety of different semiconductor materials. Photovoltaic modules based on crystalline silicon continue to be the standard on the market – even the newly developed PERC technology is based on this material. The current global conversion to the new technology is due to the clear success of research and development activities, particularly in Germany. The basic structure of the new cells also allows them to be continuously developed to further increase their efficiency – the theoretical performance limit has not yet been achieved in production. A forward-looking example is the TOPCon solar cell (see Highlight project, page 33). Here, the PERC cell had to be correspondingly modified and the rear constructed differently. By depositing a layer of silicon dioxide onto highly doped silicon, the Fraunhofer Institute for Solar Energy Systems ISE has managed to achieve a new world record in 2015 for a TOPCon cell of 25.1 percent efficiency in laboratory environment.

Reducing the costs of photovoltaics is and will remain a decisive factor in pushing forward this expansion. This will require modules that are more efficient, meaning they generate as much electricity as possible from the available sunlight.

In the area of thin-film photovoltaics, CIGS technology offers great potential for the inexpensive generation of electricity from sunlight. The semiconductor in the CIGS cells consists of the elements copper, indium, gallium and selenium instead of silicon. In comparison to a cell made of crystalline silicon, these conducting layers are almost one hundred times thinner. The current world record in efficiency for CIGS laboratory cells is 22.3 percent, which was achieved by Solar Frontier in December 2015. The values achieved in the laboratory then need to be transferred to industrial production. Alongside research and development with respect to increasing efficiency, another focus is the integration of the comparatively thin and thus light in weight modules into buildings.

Parabolic trough technologies with thermal oil as a heat transfer medium still represent the state-of-the-art technology in solar thermal power plants. A parabolic curved mirror concentrates the sun's rays onto a tube – the so-called receiver – in which the thermal oil circulates and is heated. A significant disadvantage of this technology is the relatively low operating temperature of 400 degrees Celsius, resulting in a low power plant efficiency and a higher storage volume requirement. Investigations into long-term operation have now also revealed that the thermal oil decomposes and the hydrogen concentration in the receiver tubes of the parabolic trough power plants increases over the years. An effect can be observed after eight to ten years that reduces the efficiency of the power plant significantly. Therefore, a replacement for the thermal oil needs to be found in the long term.

Alongside parabolic trough technology, there is also solar thermal tower technology. There is even less experience with this technology than with parabolic trough technology. Here, the sunlight is concentrated onto a receiver in the upper section of a tower using multiple movable mirrors (called heliostats). Tower power plants are currently in development, under construction or in operation that use water vapour, salt or air as the heat transfer medium.

Overall, the development trend for solar thermal power plants is moving towards higher temperatures. This will be achieved through the use of either molten salt (tower and trough) or by means of direct evaporation or using air as a heat transfer medium (tower). A project started in 2016 is investigating a totally new heat transfer medium – silicon oil – which can work at temperatures above 400 degrees Celsius to reach up to 425 degrees Celsius.

IN FOCUS

International competition: risks and opportunities for German companies

International competition in the photovoltaic sector is tough and many German companies have left this business within the last few years. SolarWorld is now the last major company that produces solar crystals, wafers, solar cells and modules in Germany for the mass market – and is the largest solar producer in Europe. SolarWorld was the first manufacturer to mass produce PERC cells as the new and efficient generation of solar cells. This has been contributed to by the work of the company SolarWorld Innovations (SWIN), where the global research activities of SolarWorld (SW) are concentrated. Dr. Holger Neuhaus has been Executive Director of SWIN since 2009.

The past three to four years were hard for the German photovoltaics industry. How did you experience this period from the perspective of SWIN?
Neuhaus: The crisis has had a two-fold impact. On the one hand, it was naturally a challenge for SW to survive this period too. We were forced to introduce cost-savings measures and at the same time achieve and implement even more in a shorter period of time. On the other hand, innovation was needed like never before. This crisis period was also the time in which SW transferred the most developments into production.

Is it possible to draw conclusions from this period? In your opinion, what should German companies be relying on in order to succeed against international competition?
Neuhaus: A really important pillar is certainly innovation. The most important thing is to transfer the results from the laboratory into production, which is not always easy. In light of the current pressure on costs, it will be essential in future that the resulting risks and costs are shared and the work is completed quickly: Plant constructors and production need to work even more closely together. It is fundamentally possible to be innovative in lots of areas. The traditional method is to make modules cheaper or more efficient. However, it is also possible to improve on quality and thus increase the lifespan and guarantee period. The actual energy yield

per year is becoming the most important factor. Our bifacial solar modules that have just gone into production and deliver an increased yield of up to 30 percent are particularly worthy of mention in this area. Of course, complete system solutions will also become more worthwhile and important.

If you look at quality – which continues to remain important in Germany – does the international competition also offer opportunities for German companies?
Neuhaus: Crystalline silicon technology has become established globally. Solar cells made from crystalline silicon account for 85 to 90 percent of the global market. Around 60 percent of the ideas, expertise and patents come from Germany, 15 percent from the rest of Europe and the remaining 25 percent from the USA. There is not yet anything from Asia and this represents a huge opportunity. With regards to mechanical engineering, around 50 percent of all facilities currently come from Germany. It is important that the facility construction sector and the last remaining producers and material manufacturers in Germany and Europe work very closely together so that they can continue to exploit this advantage in the future as they have done well in the past.

SW has currently achieved a technological edge through the switch to PERC cells. How long will this effect last?
Neuhaus: We were the first to implement PERC technology in large volume mass production in 2012 and we will have production capacities for PERC cells of 1.4 gigawatts in the future. It will still take other companies two to five years to reach this level. In development, we are near to achieving 22 percent efficiency with an industrial PERC solar cell. The best competitors can achieve 21.4 percent and I thus estimate that we are one and a half to two years ahead.

Dr. Holger Neuhaus, SolarWorld Innovations (SWIN)

IF PERC can be considered the new generation of cells – how long will it take until the switch to the next technology?
Neuhaus: The limit for this technology is 24 percent: There is still relatively large scope to evolve PERC technology further through continuous improvements. Improved string technology is still to be added to the module. PERC and the improved string technology will finally deliver 380 watts, where today only 260 watts are possible. It is possible that the rear of the PERC cells will still be replaced by TOPCon technology (see page 33), largely by facilities that we are familiar with, whereby there will be no changes for the most part to the front of the solar cell found in current products.

Brief info: PERC solar cells
The abbreviation PERC stands for “Passivated Emitter and Rear Cell”. The front and also the rear side of the cell is very well passivated in these solar cells. In addition, the rear of the cell only has local aluminium contacts instead of a full-area aluminium coating as found on the previous AI-BSF technology (Aluminium-Back Surface Field).

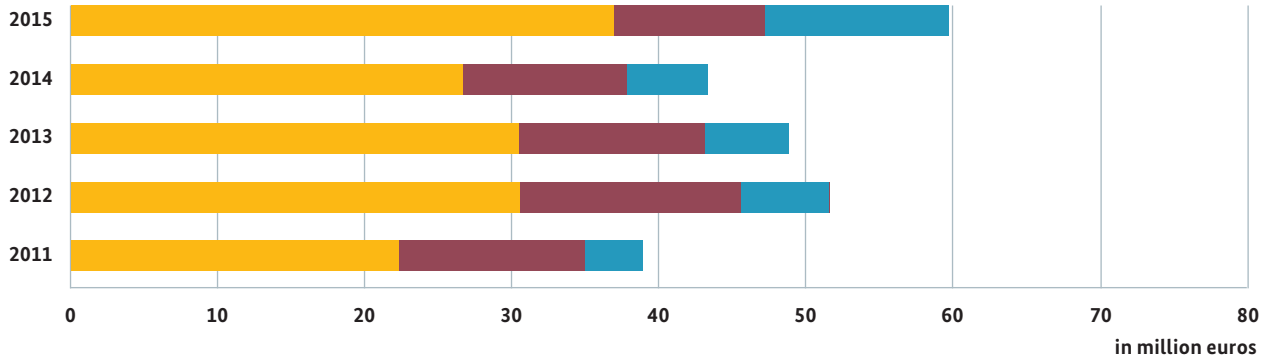
The fact that German companies are delivering relevant research results for the technological advancement of solar thermal power plants can also be seen through their level of international recognition. 2015 was the third year in succession that German products were awarded the Technical Award by SolarPACES. SolarPACES is an international network of experts in the field of solar thermal power plants within the International Energy Agency (IEA).

Strategy for the research funding

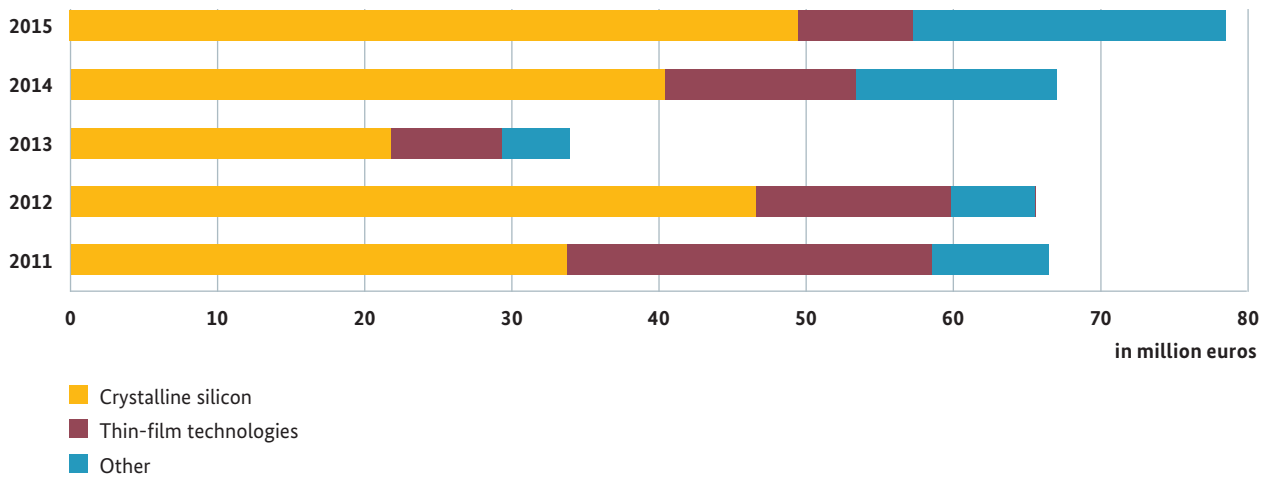
The aim is to support the German photovoltaic industry, the equipment manufacturer sector and the supplier companies in the development of innovative, competitive solutions and thus make an important contribution to the success of the German energy transition. Consequently joint projects between research facilities and industry – which are managed by the industry – are the favoured option. In the area of solar thermal power plants, the aim is also to support companies and research institutes to reduce the cost of this technology and to increase its performance. However, this essentially means making this technology viable on the market in the first instance.

In order to fully exploit geographical advantages in the area of photovoltaics, the Federal Ministry for Economic Affairs and Energy (BMWi) and the Federal Ministry of Education and Research (BMBF) implemented the „Research and Development for Photovoltaics“ initiative in 2014. In Febru-

Photovoltaics: Distribution of funding between 2011 and 2015



Photovoltaics: Trend in the volume of newly approved funding since 2011



ary 2016, a status seminar was held to present the results achieved thus far. One example is the world record for the efficiency of a refined, industrial produced PERC solar cell of 22.04 percent achieved by SolarWorld. The record was set at the end of 2015 within the **HELENE** joint project, which was provided with around 9.9 million euros of funding by the funding initiative. In summary, the focus of the initiative is placed on production-related innovations in module technology and facility construction, as well as complex technical system-based applications. The aim is to further develop business models with value added chains in Germany in cooperation with industry and industrial-related services. The BMWi provided a total of 43 million euros to nine industry-led joint projects as part of this initiative.

At the same time, the funding should also support high-quality basic research into photovoltaics. The aim here is to enable outstanding German research institutions to provide industry with ideas in the medium term that have already successfully completed the proof-of-concept phase.

Due to the potential for development for German industry described above, funding for photovoltaic research is being awarded, in particular, to technologies using crystalline silicon, CIGS thin-film technology and system technology. This also includes participation in the European SOLAR-ERA.NET (European Research Area).

Around 59.7 million euros were awarded to ongoing projects in the area of photovoltaics in 2015, which represented a clear increase compared to the previous year (2014: around 43.3 million euros). While the BMWi approved new funding for 90 new projects with a total volume of 66.9 million euros in 2014, a total of 97 new research projects with a total volume of 78.6 million euros were approved in the reporting year.

The components of solar thermal power plants that are produced in Germany hold a prominent position with respect to performance and quality. Therefore, research funding aims to further increase the competitiveness of German companies through the standardisation and qualification of all power plant components. In terms of the different forms of technology, the introduction of molten salt as a heat transfer medium forms the focus of the research funding.

It will be necessary to initially develop concepts for the use of molten salt in tower power plants due to the lack of experience in this area. Furthermore, technologies using air as a heat transfer medium – which also allows temperatures significantly higher than 400 degrees Celsius to be achieved – will be developed further.

The heat generated in solar thermal power plants can be held in thermal storage units for electricity production on demand – a significant advantage offered by this technology. Therefore, the development of adapted storage technologies is also a focus of the research. All of these issues can also be dealt with as part of the European SOLAR-ERA.NET (European Research Area).

In 2015, the BMWi approved funding for 16 new projects with a total volume of 3.8 million euros (2014: 22 projects with around 7.4 million euros). At the same time, 10.1 million euros (2014: around 9.3 million euros) were awarded to ongoing projects.

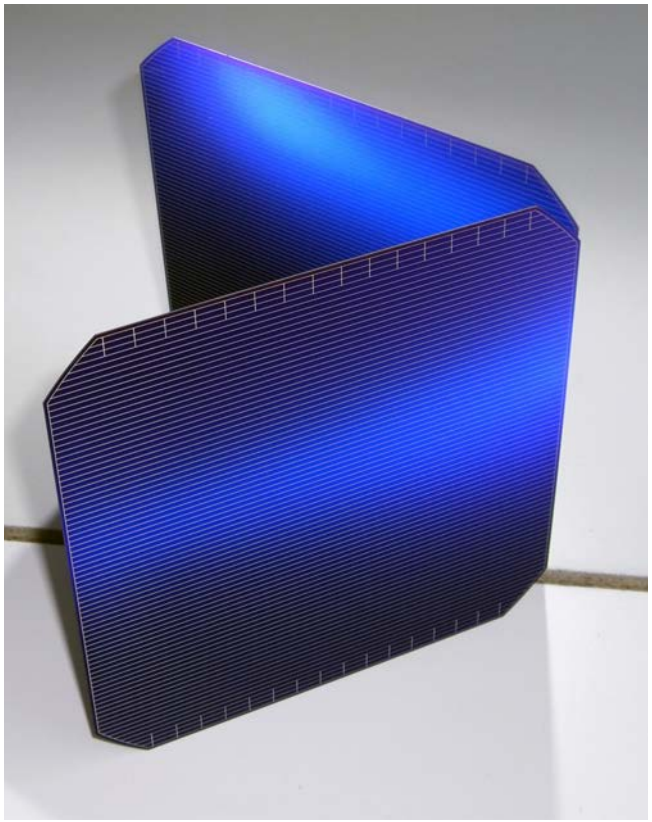
Photovoltaics

Selected funded projects

Demonstrating quickly realisable innovations

The **HERA** project coordinated by the company Meyer Burger (Germany) aims to demonstrate that it is possible to achieve costs of less than six cents per kilowatt hour for electricity from photovoltaics through the quick realisation of innovations. The total of ten project partners from the worlds of industry and research are basing their work on heterojunction technology. This combines the advantages of crystalline silicon and of amorphous silicon, which comes from the area of thin-film technology. In heterojunction cells, amorphous silicon is applied as a thin passivating layer to the front and rear of the crystalline silicon wafer. The cells are highly efficient, while they require relatively few production steps. However, their construction from individually distinguished layers demands particularly high quality surfaces and layer boundaries.

The project partners plan to reduce the manufacturing costs and also to increase the performance of the modules and their lifespan. The entire value added chain for the manufacture of cells and modules will be investigated for suitable solutions. A core element of this project is the



Solar cells from the HERA project

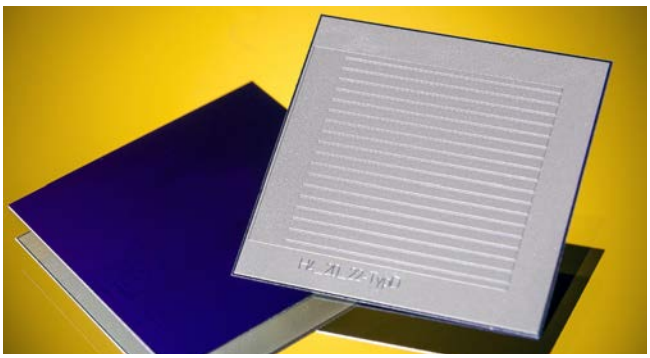
further development and optimisation of an innovative concept for thin solar cells with a rear emitter. This will increase the range of possible materials for the front of the cell as a result. The aim is to reduce the thickness of the silicon wafer from 145 micrometres at the beginning down to 100 micrometres. Innovative processes, new, cheaper materials, reduced amount of materials, adapted module technology, inline process monitoring and optimal substance and material flows are starting points for the project. The BMWi is funding HERA with around 6.4 million euros.

Highly efficient cell concept for efficiency of over 26 percent

The evolutionary development of technologies makes it possible to continue using existing types of facilities and thus keep production costs to a minimum. However, progressive cell concepts and new ideas need to be worked on in parallel in order to be equipped for the future. In the **26+** project coordinated by the Institute for Solar Energy Research Hamelin (ISFH), three research institutes are thus working on a totally new, highly efficient cell concept for crystalline silicon technology that should achieve efficiency of over 26 percent – a figure that was still considered technologically out of reach just a few years ago.

Such a high level of efficiency is possible because of progress that have been made in the area of charge carrier-selective contacts, a field in which the ISFH and the project partner Fraunhofer Institute for Solar Energy Systems ISE are currently the leading players. The new solar cell concept features emitters and contacts on the rear of the cell, whereby shadowing of the front of the cell is avoided. The innovative charge carrier-selective contacts are based on junctions between polycrystalline and monocrystalline silicon. The contacts prevent the recombination of free charge carriers so that more output can be achieved. The front of the cell has also been redesigned. Alongside the excellent passivation of the silicon surface, the aim is also to realise new ideas dealing with how light capturing. Optimising the texture of the front of the cell surface and making the rear optically active should enable the cell to better capture and thus better utilise the incident light. In the project, the scientists are developing a basic cell process for the structure described and further possibilities for improvement are being evaluated. Alongside the ISFH and Fraunhofer ISE, the Leibniz Universität Hannover (LUH) is also participating in the 26+ project. This project is being funded by the BMWi with around 3 million euros.

The cell structure designed in the 26+ project at the ISFH



HIGHLIGHT

TOPCon – new coating results in a world record

A solar cell with the newly developed TOPCon coating can achieve an efficiency of 25.1 percent and can thus convert more than a quarter of the incident sunlight into electricity. This is a new world record for crystalline solar cells that have electrical contacts on both the front and rear. In the ForTeS project, the Fraunhofer Institute for Solar Energy Systems ISE has used an easy to apply coating to realise two possibilities for further reducing the cost of electricity from photovoltaics: more highly efficient solar cells or modules and lower production costs.

This has been possible thanks to a full-surface and thus non-textured rear contact. The production process for this contact layer is cheap and also resistant to the high temperatures necessary in some processing steps. Existing types of industrial facilities can thus still be used where the processes merely need to be slightly adapted. The contact layer has passivating characteristics: Free positive and negative charge carriers that provide the electricity find it more difficult to recombine i.e. to cancel each other out. The Fraunhofer ISE has named this rear cell concept "TOPCon Technology", short for Tunnel Oxide Passivated Contact. The decisive aspects of the concept are two different layers: The actual passivated layer is made out of silicon dioxide and is only two nanometres thick so that the charge carriers can "tunnel" through it. A thin layer of high quality silicon is then also applied on top of this layer – the silicon is doped with a high proportion of another element such as phosphorous. The highly doped silicon ensures that electricity can flow without any losses.

The Fraunhofer ISE had previously implemented the TOPCon concept on the rear of n-type solar cells. In this type of cell, negatively charged electrons can move freely – in contrast to p-type cells where positive charges move freely. The TOPCon layer has therefore only been used up until now as a contact for the electrons. In order to open up the possibilities for further applications, the project has now been extended. These applications include using the concept on the rear of p-type cells to connect to positive charge carriers. This will require a further improvement or adaptation of both the electrical and also the optical characteristics of the layer for this type of cell. Higher losses due to charge recombinations are currently being experienced than in n-type cells. In addition, the aim is also to adapt the TOPCon concept for use on the front of n-type cells. This will require the development of a passivated contact that is sufficiently transparent for sunlight to pass through. TOPCon thus offers great potential for further improvements in efficiency. The BMWi is funding the project ForTeS with around 6.2 million euros.

Transmission electron microscope image of the structure of TOPCon developed by the Fraunhofer ISE

HIGHLIGHT

High efficiency thanks to a fundamentally optimised material

The overall costs and also the efficiency of a crystalline solar module are in part directly related to the production of the silicon ingots, which involves the targeted solidification of molten silicon. The ingot is firstly cut into columns and then thin layers of silicon – the wafers. The sawing process also has a massive influence on the quality of the subsequent solar cells. In the ENOWA II project coordinated by the company SolarWorld Innovations (SWIN), the total of eleven project partners from industry and research are thus aiming to optimise this fundamental processing step in order to produce highly efficient wafers more cost-effectively. The goal is to achieve an output of over 300 watts per standard module using these highly efficient wafers.

Molten silicon solidifies as a crystal. Depending on the process, it is possible to produce multicrystalline (partially ordered consisting of multiple small crystals) or monocrystalline (uniformly ordered) silicon: The latter is more efficient but the crystal growing process is more expensive in comparison. The solution would be to produce at least the same level of efficiency with a less expensive process. Therefore, the scientists have already developed a process in the earlier ENOWA project to produce crystal ingots in a "quasi-monocrystalline" form. This process involves placing monocrystalline silicon plates as seed crystals on the base of a container – the crucible – and filling it with raw silicon. Once the raw silicon has been melted, its atoms orientate themselves to the structure of the moncrystalline seed crystals.

However, the scientists found that the crystal structure contained more faults as the height of the ingot increased. Furthermore, the process was also susceptible to contamination with metallic impurities – with a resulting drop in the quality of the material. The scientists want to reduce this effect in the **ENOWA II** project. One reason for this is believed to be the material and coating of the crucible.

One of the thing that is being investigated is an amended "Quasimono II" process that does not require a crucible. In addition, the project partners are developing a technology for sawing that has been specially adapted to the quasimono material. Here, the aim is to adapt the diamond wire cutting process so that the wire is fitted with small, fixed diamond grains. The size of the grains, their density on the wire and the way the grains are bonded are some of the aspects being investigated. The project partners are utilising the demonstrator developed in the earlier ENOWA project for their work.

The form of the project with numerous participating institutes and companies enables a combination of basic research in institutes, efficient numeric simulations both at SWIN and the institutions and large-scale technical implementation at SWIN.

The BMWi is funding ENOWA II with around 8.3 million euros.

Silicon ingots for the production of wafers at SolarWorld

The latest production facility of Manz for the fast depositing of CIGS layers for high quality thin-film solar modules

From laboratory to production: 5 instead of 40 minutes

A continuous reduction in costs is also required in the area of CIGS technology in order to keep pace with international competition. Further improvements in efficiency and cheaper production processes are the goal of the **TACGO** project being carried out by Manz CIGS Technology in cooperation with the Coating Department at Manz. The project aims to reduce the production costs for CIGS modules from the current 40 cents per watt to 35 cents per watt by 2018 – for factories with a capacity of 150 megawatts per year. Correspondingly lower costs should be achieved for factories with larger capacities.

The results achieved by the Center for Solar Energy and Hydrogen Research Baden-Wurttemberg (ZSW), the official research partner of Manz, will be transferred to the innovation line at Manz CIGS Technology as part of the project. In September 2014, the ZSW managed to achieve a world record for the efficiency of small CIGS laboratory cells of 21.7 percent. Alkaline elements deposited on the CIGS layer were responsible for this success. In this process, the scientists accepted a very slow deposition time for the layer of between 30 and 40 minutes – yet a time of 5 minutes has been proposed at the innovation line at Mainz due to the cost. Extensive improvements will be necessary to transfer the laboratory results into production. In addition, the TACGO project also aims to increase the productivity of the coating facilities. This includes both the depositing process for the CIGS layer and also the sputtering process for the molybdenum rear contact and the zinc oxide front contact. Findings from other projects funded by BMWi such as CIGSfab and CIGS_Ng_P are being utilised in the project to enable the ongoing optimisation of CIGS technology and thus achieve continuous reductions in the costs for generating electricity. The TACGO project is being funded with around 3 million euros.

Cooling and heating with solar electricity

Almost 100 million air conditioning units are sold each year, the majority of which are in the low output range. As enormous cost reductions have been achieved in recent years in the area of photovoltaics, it is now becoming worthwhile to use solar electricity for air conditioning. In the **SolarSplit** project that is being coordinated by the Institute of Air Handling and Refrigeration (ILK), the aim is thus to investigate what kind of suitable, efficient solutions there could be. The project is concentrating on the popular mono-split air conditioning units and VRF multi-split air conditioning units. In addition to cooling, these types of units are also often capable of providing heating (VRF stands for Variable Refrigerant Flow).

In general, the peak yield from solar electricity is around midday – in contrast, energy consumption for air conditioning applications tends to be late in the afternoon. Air conditioning units and photovoltaic systems have previously functioned independently of one another: In those countries with many roof systems such as Australia, too much electricity is fed into the electricity grid at midday, while at the same time peak loads in the afternoon and evening are not covered. There is another challenge regarding heating: The efficiency of the units is strongly linked here to the rise in temperature. In this respect, it would be more efficient if the heat could be generated when the outside temperature was higher rather than lower i.e. if the generation of heat was decoupled from the demand for heating energy. In order to increase own consumption of solar electricity and reduce the electricity load to the grid, the project partners are thus developing solutions with integrated ice or heat storage systems, forecast-based controls and the integration of smart home systems. As a result, the aim is to significantly increase the proportion of cooling and heating generated from renewable energy. The project partners are the Munich University of Applied Sciences, the Bavarian Center for Applied Energy Research (ZAE) and the companies Thermofin and Swegon Germany. The BMWi is funding SolarSplit with around 2.8 million euros.

Split air conditioning unit

Solar thermal power plants

IN FOCUS

Global expansion continuing despite difficulties

In 2015, the total global output from solar thermal power plants in operation reached 4.9 gigawatts. Although this technology has not developed as quickly as desired, which is why costs are comparatively high in comparison to photovoltaics, new power plants are nevertheless still being built. The advantage of these power plants lies in their base-load compatible, available-on-demand supply of energy through easy to install heat storage systems.

Electricity in solar thermal power plants is generated through heat, which can be directly stored without any additional conversion steps. In some regions of the world, it is precisely this advantage that is already being exploited to full effect. For example, the responsible solar agency in Morocco also opted for solar thermal power plants. The temperatures in the country are so high during the day that many activities are postponed until the evening. The heat storage system at the power plant unit Noor 1 that was placed into operation in December 2015 is still able to supply electricity three hours after sunset. Noor 1 has an output of around 160 megawatts. Two further power plant units with a total output of 500 megawatts are due to be connected to the grid in 2017.

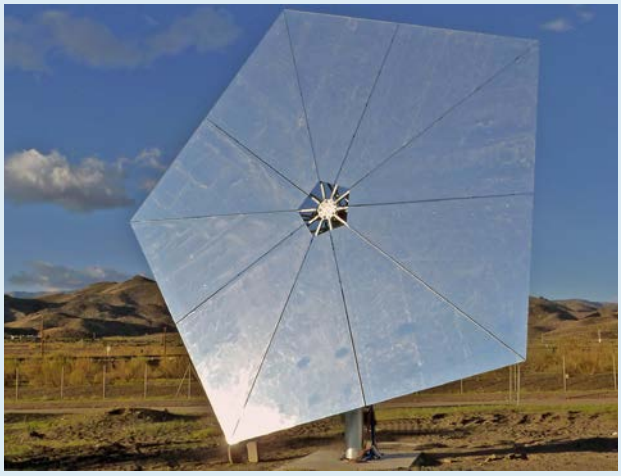
Due to Morocco's strategic energy transition plan, the country offers good conditions for the further construction of solar thermal power plants. Solar power plants with a total capacity of 2,000 megawatts should be in place by 2020. Other countries where expansion is expected are the USA, other MENA (Middle East and North Africa) countries, South Africa, China and Chile.

Future expansion plans can be clearly seen on the global map created by SolarPACES (version: June 2015), the network for the solar thermal power plant sector under the auspices of the International Energy Agency (IEA). If all of the power plants that are currently under construction or in the planning stages are added to the already completed power plants, the global output totals more than 10 gigawatts.

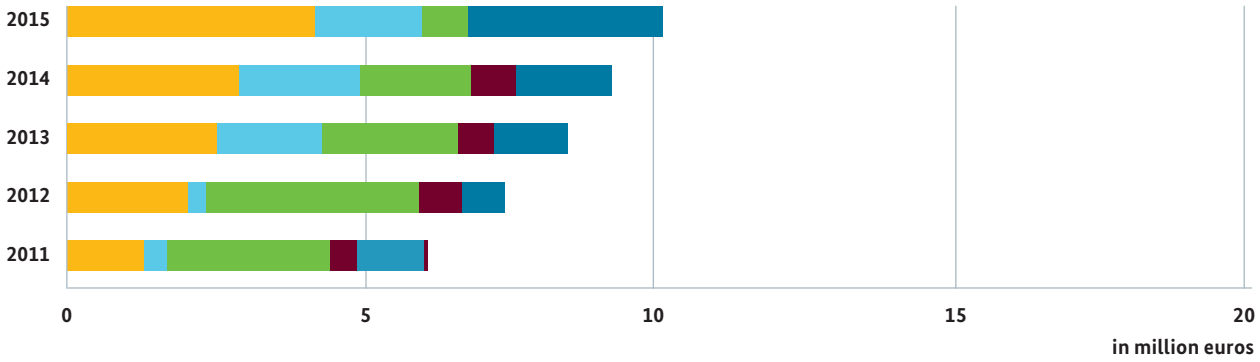
An output of 870 megawatts is planned for Chile alone. The 110 megawatt Atacama solar tower power plant which will use molten salt as a heat transfer medium and integrated salt storage systems is already under construction. The country is planning to integrate the newest techniques into its construction projects, which is important for the further development of the technology as a whole. South Africa also offers good conditions for promoting this technology and has issued relevant expansion plans for solar thermal power plants. The Kaxu Solar One parabolic trough power plant with an output of 100 megawatts in Cape Town and the 50 megawatt parabolic trough power plant in Bokpoort in the Northern Cape Province were already placed into operation in 2015. Projects with an output of 150 megawatts are currently under construction and a further 400 megawatts are in the planning stage. In the USA, the Crescent Dunes solar tower power plant with an output of 110 megawatts was placed into operation in Nevada in 2015. This power plant operates using molten salt as a heat transfer medium and features a 10 hour storage system. The expansion plans in the USA envisage a further 1,650 megawatts in the coming years.

Projects for complete solar thermal power plants are mainly handled by companies from Spain, Israel and the USA. Nevertheless, Germany remains an important supplier of core components such as heliostats, parabolic troughs, receiver tubes and components for the power plant block. The high level of quality offered has been acknowledged: German products received the Technical Award from SolarPACES in 2013, 2014 and also 2015. The 2015 prize was awarded to a consortium coordinated by the German company schlaich bergermann partner – sbp sonne for the design of the Stellio Heliostat – a pentagonal mirror for tower power plants that is designed to minimise mutual shading within the field of heliostats.

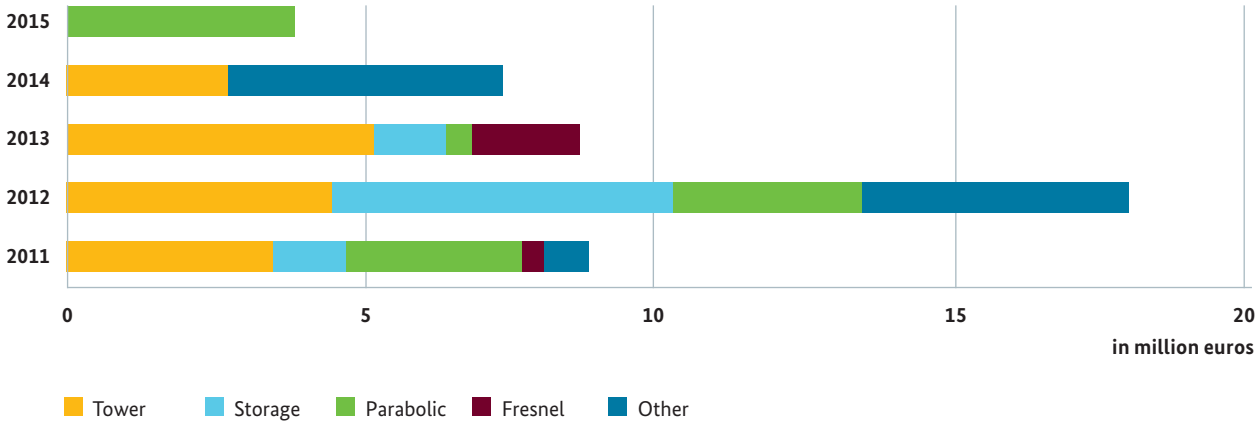
Pentagonal Stellio Heliostat



Solar thermal power plants: Distribution of funding between 2011 and 2015



Solar thermal power plants: Trend in the volume of newly approved funding since 2011



Selected funded projects

Exploiting Jülich's periods of sunlight to the best possible extent

Conducting multiple experiments in parallel, avoiding downtimes and thus making better use of Jülich's periods of sunlight – these are the main goals of the **Multifokusturm** project that is being carried out by the Institute of Solar Research at the German Aerospace Center (DLR). The aim is to expand the solar tower in Jülich – the German test and demonstration power plant for solar thermal electricity generation – to include additional experimental levels. The solar tower has been in operation since 2009 and was taken over by the DLR in the middle of 2011. It possess a central, 22 square metre ceramic receiver on the top of a 60 metre high tower, an integrated small-scale power plant, a field of around 2,000 heliostats and a research level that is housed at a height of 27 metres in the centre of the tower. Alongside work on the whole solar thermal power plant system, research into individual components such as the ceramic absorbers is also possible.

The research level has been intensively utilised for around three years – although it is often necessary to interrupt the research when experiments need to be modified, new experiments set up, old experiments dismantled or if technical difficulties need to be resolved. A second tower with a total of three experimental levels including infrastructure and measurement technology is now set to provide assistance. The high quality measurement technology already in place in Jülich, the flexible supply or waste disposal structures and the excellent operating personnel will thus be exploited to the best possible extent. The existing field of heliostats can be controlled so that the individual heliostats are grouped according to the requirements of the experiments. This makes it possible to direct them towards the particular objectives of the different experimental levels. The new construction will form the basis for a variety of future-oriented experiments. Amongst other things, test stands for

solar process technology are planned. With these it should be possible to develop systems to utilise the sun's heat to generate fuels such as hydrogen, for example, using thermochemical cycles or solar high temperature electrolysis. The BMWi is funding the development work for the new test plants with around 1 million euros. A further 5.2 million euros has been provided for the construction by the State of NRW.

The research level irradiated by the sun at the solar tower in Jülich

A large and extremely precise mirror

The “Ultimate Trough” concept featuring a significantly larger parabolic trough than standard troughs has been developed to reduce the costs for solar thermal parabolic power plants. The dimensions allow an increase in performance per collector, while the use of materials and the production costs are lower with respect to output. For large solar thermal power plants from an output of 200 megawatts, this results in around 25 percent lower costs for the solar field. Electricity generated by power plants using Ultimate Trough technology should thus be around 10 percent cheaper. The company Flabeg Holding began developing the new design in 2010. The next step is now to establish the industrial production process.

In the **SOLUT II** project, the company (now called Flabeg FE) is working on the development of suitable processes for the production of the so-called Reflective Panel 6 (RP6) mirror, which will be used for the Ultimate Trough. In comparison to the current RP3 generation of mirrors, its overall size is around 50 percent larger: from 10.7 square metres to 16.4 square metres per row of mirrors. The plane glass used to make the mirror is only available in certain widths, so to best make use of the glass the RP6 is split into three parts. It is still necessary, above all, to improve the focussing accuracy of the mirror in order to hit the absorber tube in the centre within a predefined deviation so that all of the reflected solar radiation will be utilised. In addition, the project aims to increase the operational speed of the bending process for the mirrors, as well as further speeding up the coating and finishing processes. Furthermore, the scientists are developing a horizontally arranged measurement system to record the bending precision of the mirrors – instead of vertical measurements currently in use. This will establish a new standard that has been requested by customers of parabolic trough projects since 2013. The BMWi is funding this project with around 220,000 euros.

Three-part RP6 mirror for the “Ultimate Trough”, a significantly larger parabolic trough than standard troughs

Deep geothermal energy

Geothermal energy is constantly available 24 hours a day, 365 days a year. The heat can be used directly but can also be converted into electricity. As a permanently available source of energy, it will form an important component of the energy mix of the future. It supplements the fluctuating availability of wind and solar energy and can thus make a significant contribution to stabilising the energy system in the future. Furthermore, geothermal energy is one of the few renewable technologies that can make a major contribution to the heat supply. In the area of deep geothermal energy, boreholes of more than 1,000 metres are common, which convey thermal water from geothermal reservoirs at temperatures of greater than 60 degrees Celsius to the Earth's surface.

Market developments in Germany and across the world

Geothermal energy is currently utilised mainly for heating purposes, with entire districts and cities being supplied with environmentally friendly heating as a result. The generation of electricity from geothermal energy continues to be a focal point of current research efforts.

In general, it is possible to distinguish between two different methods for exploiting deep geothermal energy: hydrothermal and petrothermal geothermal energy. Hydrothermal geothermal energy utilises deep thermal water. This water is pumped to the earth's surface and then used to either deliver heat or generate electricity. The regions of Germany with suitable conditions include the Molasse Basin in Southern Germany (mainly in Bavaria), the Upper Rhine Graben in South West Germany and the North German Basin. Hydrothermal geothermal energy is already being exploited in these parts of the country to a large extent. There is an especially high natural increase in temperature at increasing depths in these regions.

Petrothermal geothermal energy utilises the geothermal heat present in the sub-surface, without the need for water to be present. In this case, water is pumped down from the earth's surface into the dry rock formation where it is heated. After been heated up, the water is pumped back to the surface and utilised to generate heat or electricity. It is assumed that petrothermal geothermal energy holds

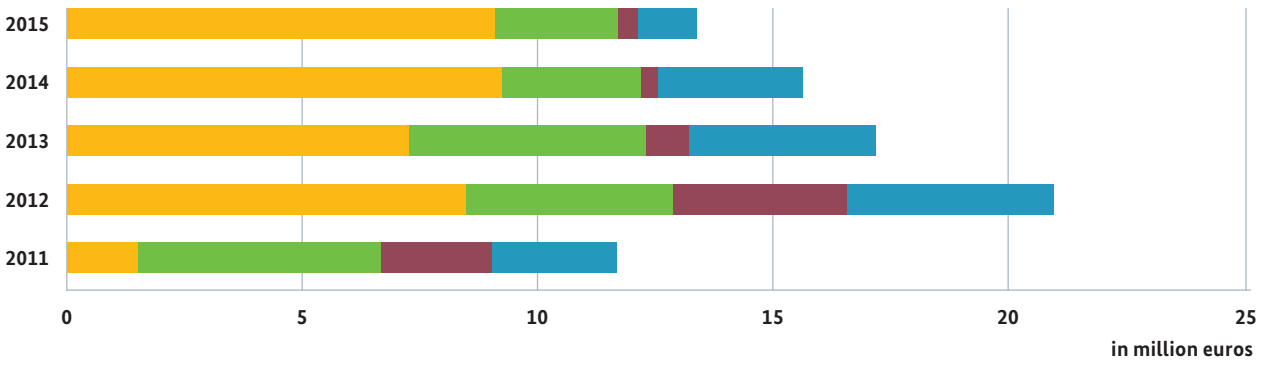
great potential. However, this technology is still at the research and development level.

In Germany, deep geothermal energy is being increasingly used to generate heat. In terms of the prevailing geological conditions in Germany and the existing structure of demand, projects involving heating, such as supplying local and district heating systems, have higher prospects for being economically successful than projects purely aiming for the generation of electricity.

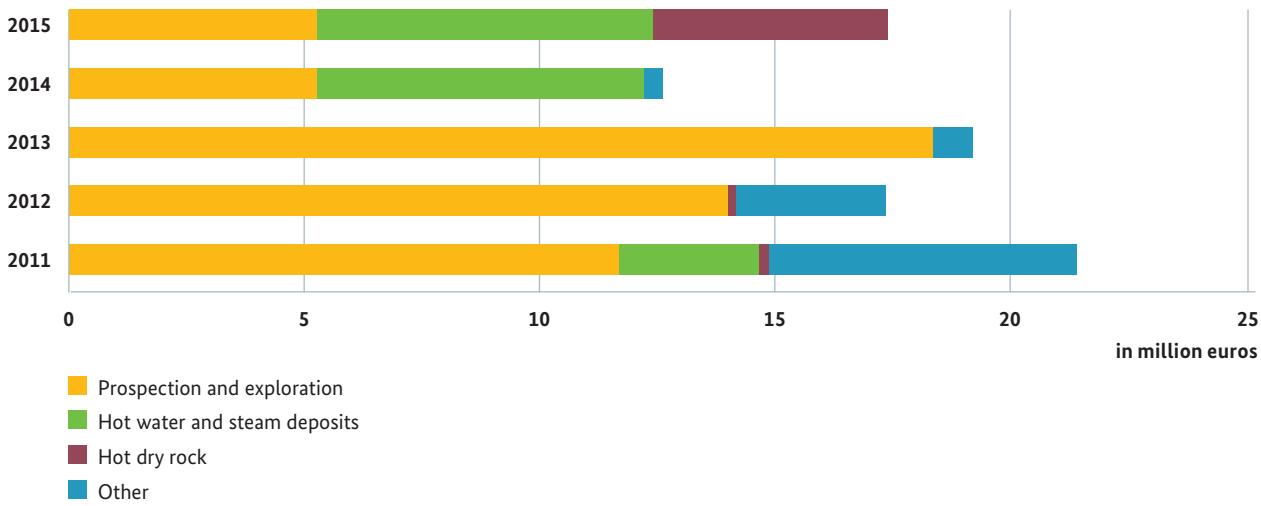
According to the German Geothermal Association (BVG), there were 33 geothermal power plants in operation across Germany in October 2015. Most of these plants exclusively generate heat, with the related installed capacity of 281.16 megawatts (thermal). Nine of the geothermal plants generate electricity – either exclusively or supplementary to heat. They have a combined installed electrical output of 32.19 megawatts.

According to the latest figures from the BVG, Germany is still in fifth place globally with respect to the utilisation of heat from geothermal energy. The statistics include the installed deep and near-surface geothermal energy installations worldwide. Near-surface geothermal installations are defined by depths of up to 400 metres below the surface. In general, these types of system use heat probes with a closed circuit to supply individual households or housing complexes. The statistics are collected every five years and were last updated in 2015. First place – previously held by

Geothermal energy: Distribution of funding between 2011 and 2015



Geothermal energy: Trend in the volume of newly approved funding since 2011



IN FOCUS

Pump technology – working at the heart of a geothermal plant

The pump is currently the most vulnerable component when operating geothermal energy installations. The thermal water is pumped from the borehole many hundreds of metres to the surface at fluctuating loads depending on the heating demands during the year. Electric submersible pumps, which are installed together with their integrated electric motor under the level of the water table, have become the established standard for use in geothermal energy. In comparison to other pump concepts, the efficiency is higher and service intervals are longer – although these issues still arise too frequently for continuous economic operation.

The challenges related to thermal water, pressure and particles are great. The pump and its metal components are permanently exposed to corrosive thermal waters, while water-borne particles (e. g. carbonates) can accumulate. The seals must be reliable enough to protect the motor, where in addition overheating has to be avoided. Furthermore, geothermal energy applications require significantly higher flow rates and outputs compared to oil extraction. The average lifespan of pumps adapted from the oil and gas business is only a few months. Economic viable operation in geothermal plants is thus, in many cases, not possible.

The goal of the projects funded by the BMWi is thus to increase the reliability of the pumps, avoid downtimes and increase their efficiency. Considerable success has already been achieved – with the work of the companies as e.g. Baker Hughes and Flowserve.

Baker Hughes has for example developed a globally unique high temperature test stand (HotLoop) that can accelerate research work. It provides the combination of high temperature and high drive capacity that has so far not been available. The test stand produces an accelerated ageing of the pumps and enables wear and damages to be identified more quickly. It has already helped engineers to deliver some design improvements that have led to the reliable operation of immersion pump systems over longer periods of time. Their efficiency has also been improved.

A particularly noteworthy improvement involved the radial bearings in the pumps that now achieve significantly longer service times. In the boreholes in Dürrnhaar and Sauerlach, pumps fitted with these optimised radial bearings were successfully deployed for four months in each case without any notable wear. Pumps fitted with conventional bearings only achieve service

Despite heavy calcification in the inlet area, the newly developed radial bearings in the geothermal pumps in Sauerlach and Dürrnhaar displayed no signs of wear

intervals of between four and six weeks in the same boreholes due to calcification of the bearings. In addition, new "Flex" pump levels were developed that can flexibly pump different volumes depending on the time of year which are at the same time much more efficient. The insulation and radial bearings in the motors were also redesigned, whereby related downtimes could be effectively prevented. In parallel, the engineers are working on a high temperature pump sensor system. It is designed to precisely monitor the condition of the pump during operation.

Based on the results of a precursor project, the company Flowserve has developed a test aggregate. The motor series developed in the earlier project was specifically modified for this purpose. The engineers have already registered some patents: for the radial bearings in the motor, the pressure compensation unit and for an internal motor cooling system. In order to further optimise the cooling circuit, the scientists identified a selection of suitable filter units based on their cooling flow, efficiency and reliability. Another result from the project relates to the diameter of the pump casing: optimal flow conditions were achieved when the diameter was slightly increased. As a result of the installation of an additional axial bearing, it was also possible to significantly increase operational reliability. The motor bearings and face seal were adapted to the behaviour of the motor due to the effects of thermal expansion. The electrical technology in the motor was also optimised to increase efficiency.

The results achieved, which can only be described here to a limited extent, are promising developments on the path to the economic and reliable operation of geothermal heat or power plants. In order to be able to employ pumps that require as little maintenance as possible over many years at even higher temperatures, it is necessary to follow up on these developmental approaches.

the USA – has now been taken by China, which has now expanded its previously listed installed thermal capacity of 8,898 megawatts to 17,870 megawatts. The USA lies in second place with 17,415 megawatts. These countries are followed by Sweden (5,600 megawatts), Turkey (2,886 megawatts) and Germany.

Progress in research and development

The potential offered by deep geothermal energy as a continuously available source of renewable energy needs to be further exploited. A lot of research and development work has already been carried out towards this goal that has also been recognised internationally. Advances have been made in all areas. There have been continuous improvements in the areas of drilling technology and plant construction and it has been possible to significantly extend the service intervals of thermal water pumps (also see "Pump technology – working at the heart of a geothermal plant", page 42). New methods have also been developed to determine appropriate target areas for drilling. In the field of drilling technology, directional drilling can be carried out with a lot more precision than was possible a few years ago.

As can be seen by the distribution of the existing power and heating plants, successes have been achieved in particular in the Molasse Basin in Southern Germany. Heat from deep geothermal energy can already be reliably utilised in this area. Particularly worthy of note at this point is the **GRAME** project (also see "Highlight", page 46), which supports the long-term goal of covering the entire heating requirements in the Munich region through renewable energies. Geothermal energy is set to make a decisive contribution here. The seismic measurements for this project began at the end of 2015 and will be used to map the underground sites.

Strategy for the research funding

Due to the major influence of the local conditions in each region, such as the composition of the thermal water or the geological structures, each geothermal heat or power plant is unique. A more individual approach is necessary in the planning phase, compared to other technologies. In view of the significant potential and expected contribution of geothermal energy to a future energy system based on renewable energy, the Federal Ministry for Economic Affairs and Energy (BMWi) is continuing to support relevant research

The mobile test stand at KIT allows measurements of the properties of flowing thermal water

projects. Further research is still required in order to economically utilise deep geothermal energy and thus fully exploit the existing potential of the heat. The BMWi primarily provides funding to projects that are dedicated to complete systems – such as pumps.

The research projects currently being funded encompass all stages along the value chain for geothermal energy. The primary goal is to further reduce the cost of projects in order to make geothermal energy economically viable nationwide. Contributions towards the achievement of this goal are made by technological developments in all project phases: in the planning of the project, the exploration of the target region, the drilling/construction phase and the testing and operation of the completed plants. In particular, the deep boreholes must be completed more quickly and less expensively as they account for the main part of the investment costs. The operation of completed heat or power plants needs to be more efficient and reliable with low maintenance needs. Alongside further technical developments in geothermal energy, concepts for improved public relations work are now a fundamental component of successful research projects. And last but not least, the conditions must be created to allow geothermal energy to be utilised in those areas that have not yet been explored or which are less suited.

In the area of geothermal research, the BMWi approved funding for a total of 21 new projects with a funding volume of around 17.3 million euros in 2015 (2014: 15 new projects with around 12.7 million euros). At the same time, around 13.4 million euros were invested in already ongoing research projects (2014: around 15.6 million euros).

Selected funded projects

Analyses in the flow of thermal water for optimised forecasts

Before the construction of a new geothermal heat or power plant can begin, a prognosis must be made about its economic viability, to secure a sufficient number of investors. The possible thermal output of the new plant is thus of great importance and depends on a variety of physical and chemical properties of the extracted thermal water. The precise prediction of these properties is therefore the goal of the **PETher** project that is being coordinated by the Karlsruhe Institute of Technology (KIT). Other project partners are GeoThermal Engineering (GeoT) and Global Engineering & Consulting-Company (gec-co).

A relevant variable is the specific heat capacity, meaning the ability of the thermal water to store heat. Other variables include dynamic viscosity and thermal conductivity. These values are dependent on the temperature, pressure, dissolved minerals and gas content of the water. The standard procedure used up to now, taking water samples and transporting them to a laboratory can change the parameters of the samples. Therefore, the KIT has developed a concept that measures the specific heat capacity and the dynamic viscosity of the thermal water in situ. The measurements are

carried out in reservoir-like conditions in the flow of water itself to retain the pressure and temperature of the water. The PETher project aims to install an already developed test stand into geothermal plants in the Northern German Basin, the Upper Rhine Graben and the Molasse Basin in order to further develop this methodology. The test stand will be integrated into the plant via a bypass. In all three regions, the project aims to determine the typical behaviour of the physical variables of the thermal water mentioned above as a function of pressure, temperature and the concentrations and type of substances in solution. In addition, a planning tool for forecasting the properties of thermal waters under given local conditions will be developed. The BMWi is funding this project with around 690,000 euros.

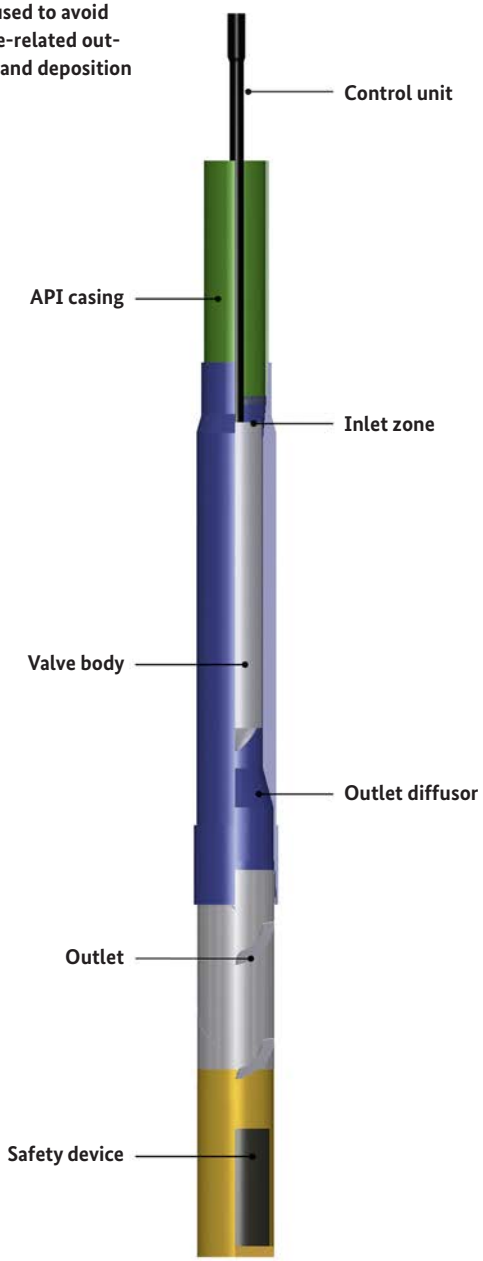
New pressure retention valve avoids precipitation

When pipes or filters in thermal water cycles become blocked, the operational processes in a geothermal heat or power plant will be impeded. The heat transfer is hindered and the efficiency of the plant is reduced. To avoid the deposition of scalings, the outgassing of the thermal fluid and the resulting cavitation, the **Pressure Retention Valve** project coordinated by the company gec-co Global Engineering & Consulting-Company has developed a new kind of controllable pressure retention valve. The valve is installed below ground at depths of approximately 500 to 700 metres. It is positioned below the water level and constantly maintains the pressure of the thermal water in the entire water circuit of the plant at a level above the degassing pressure. The company was nominated for the European Geothermal Innovation Award 2015 for this development, which is awarded by the European Geothermal Energy Council (EGEC) and Messe Offenburg.

If thermal water is extracted from below ground, there can be outgassing and precipitation. This places a strain on components that leads to leakage, material fatigue and corrosion. The substances that cause these problems can be held in solution in the subsurface and throughout the entire surface installations of the plant using these controllable pressure retention valves, thus avoiding pressure-related outgassing and scaling. In addition, the lifespan of the valve and other components is significantly increased. The controls and operating system for the valve are positioned at the surface and are therefore easier to access and maintain.

The innovative idea itself and its installation concept, with the location below the water level in the injection line, differentiates it from other valves types available on the market and adapts it ideally for the conditions found in deep geothermal wells. Due to its special design, the valve can also be configured redundantly. The work is being accompanied academically by the project partner University of Erlangen-Nürnberg. The BMWi is funding this project with around 580,000 euros.

Set-up of the gec-co underground pressure retention valve that can be used to avoid pressure-related outgassing and deposition



Knowledge, trust and transparency for higher acceptance

Acceptance amongst the general population is important for all renewable energies because further expansion is not possible without the necessary backing. A further issue is that deep geothermal energy is relatively unknown as a renewable energy – there is a lack of knowledge about this innovative technology. A communication concept including a smartphone-app was developed in the **TIGER** project coordinated by the CBM Gesellschaft für Consulting, Business und Management to address this problem. The concept supports geothermal companies in following an effective strategy in their communication and public relations work right from the very beginning.

The basis for the concept was a scientific survey to collect acceptance factors. The results showed that 89 percent of the respondents considered geothermal energy an expedient form of energy for Germany. More than 71 percent even advocated having a geothermal power plant in their vicinity. Local energy provision and the general advantages offered by renewable energy were given as reasons. "Unknown risks" were the main disadvantage stated – an indication of the low level of awareness amongst the general public. The dissemination of information about geothermal energy in general is thus just as important as detailed information about the specific project being planned.

Correspondingly, the TIGER communication concept focuses on knowledge transfer, building trust and acting transparently. The central point is to keep residents continuously involved in the project. They want to be informed as much about the advantages as the possible risks and to be included in the discussion on an equal footing.

Other project partners were the Human-Computer Interaction Centre at the RWTH Aachen University and the gec-co Global Engineering & Consulting-Company. The TIGER smartphone app includes general information about the technology, a game and a toolbox with procedural guidelinesfor public relations work for operators and institutions. It is available via well-known app stores and via the TIGER website. The BMWi funded this project with around 1.4 million euros.

HIGHLIGHT

Geothermal heat for Munich

The subsurface of Munich offers considerable potential: The city is located in the region of the so-called Molasse Basin in Bavaria. The underlying geological formations here are particularly suited for the extraction of geothermal heat. The rocks are part of Malm, a geological formation that acts like an aquifer for hot thermal water due to its special structure. Good conditions for the future vision of Stadtwerke München: The aim is to provide the entire district heating for Munich from renewable energies by 2040, with the majority being contributed by geothermal energy.

Stadtwerke München, as the coordinator, aims to lay an important foundation for this vision with the **GRAME** project. There is geothermal heat present below Munich and it can in principal be extracted. However, there is still no consistent concept for determining what locations would be best suited for extracting the heat and how it can then be integrated into the existing district heating network. The project partners are planning to create a three dimensional image of the subsurface and use it to develop a suitable extraction strategy. In general, the results should contribute to the better exploitation of the geothermal resources within the Molasse Basin and the utilisation of the potential that will be opened up for the generation of both electricity and heat.

The project partners are using 3D seismics to gather data on the bedrock. Signals are produced at the surface by a vibration truck and are then reflected in different ways by the various layers in the subsurface. The returning signals are measured and analysed. This method allows to gather information about the most promising target areas for future drillings. The measurements are being taken over a planned area of 170 square kilometres, whereby the Malm reservoir under the whole southern area of the City of Munich is being investigated. Investigations about the potential for a geothermal use on this scale have never previously been carried out in the region. Therefore, its significance goes far beyond this project. Conducting 3D seismic measurements beneath

A vibration truck investigates Southern Munich: The subsurface can be investigated with the aid of vibration seismic surveys in a similar way to using an echo sounder

an urban area is also breaking new ground: Amongst other things, traffic or construction work on the surface generate incessant vibrations that influence the measured values. The project also aims to push forward the technology of 3D seismics to gather more precise data on the underground structure.

Even before the actual measurements began, the project partners had developed models for potential major projects. The goal is to generate electricity of around 50 megawatts or to extract heat in the range of 400 megawatts. A preliminary geological model of the subsurface formed the basis for the project. Possible locations for drilling will be added to the model as a grid of boreholes, whose impact on the reservoir will be simulated. When designing new plants, it is also important to take into consideration that the geothermal heat needs to be integrated into an already extensively constructed district heating network. Once the measurement data have been recorded, a real grid of boreholes will be drilled that will take into account the prevailing geology and also the infrastructure of the City of Munich. At the end of the project, a real concept for extracting geothermal heat will have been developed which leads Stadtwerke München a good step closer to achieving its vision for the future.

Alongside the Stadtwerke München, the Leibniz Institute for Applied Geophysics (LIAG) is also participating in GRAME. The BMWi is funding this project with around 4.6 million euros.

Hydropower and ocean energy

Hydropower as a renewable energy primarily uses the flow of water in rivers or reservoirs. Water wheels or turbines convert the movement of the water into mechanical energy from which electricity is produced by generators. Ocean energy can also be utilised in the form of ocean currents or tidal energy generated by the gravity of the Moon. Finally, there is also wave energy that is primarily generated by the action of the wind on the surface of the water.

Market developments in Germany and across the world

Hydropower plants are based on a largely established technology that is already reliably implemented in many locations – including some in Germany. In contrast, marine power plants are still in the development phase.

A number of different systems have already been developed to utilise wave energy. Wave power plants based on the principle of an oscillating water column are well proven. Air in a chamber is compressed and decompressed as the column of water in the system rises and falls in time with the waves. The resulting air flow then drives a Wells turbine. Other wave power plants also use a floating body that moves with the waves and drives a generator via pivots, cables or other intermediate systems. These types of plants are comparatively small and can be installed in many locations. However, the efficiency of these plants still needs to be increased.

Tidal power plants are being tested and optimised around the world in pilot projects using a variety of different concepts. The 150 to 220 tons 1-megawatt class turbines commonly used up to now have a diameter of 13 to 20 metres and are firmly anchored to the seabed. Their manufacture, installation and maintenance are cost-intensive and time consuming. A new project dealing with this subject that promises lighter and more convenient plants was approved in 2015 (also see page 49, “Flexible platforms with robust turbines”).

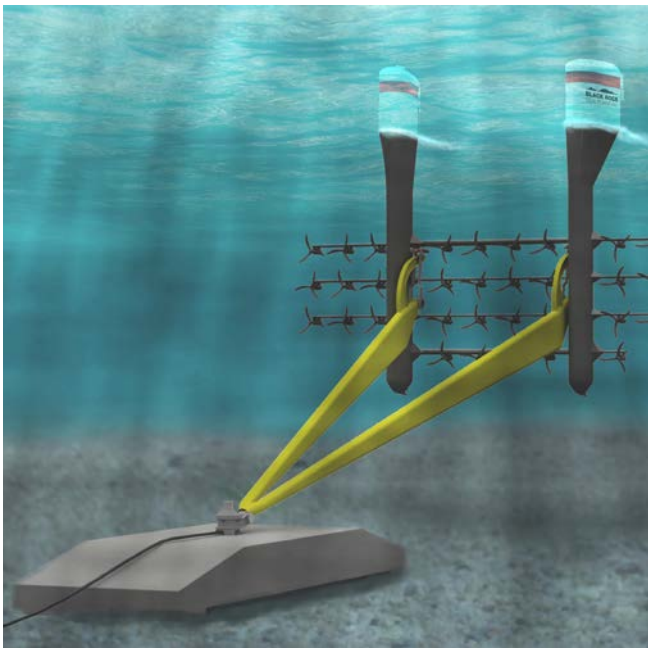
Progress in research and development

The advantage of both hydropower and ocean energy compared to other renewable energies is that electricity can be supplied constantly. In this respect, it is also possible to reliably predict the yield. Hydropower is already a tried-and-tested source of energy. It has been possible to further improve the ecological compatibility of the power plants using targeted funding programmes. In contrast, those power plants that utilise ocean energy are still at the demonstration stage but they do offer great potential.

Strategy for the research funding

The main focus of the research funding from the Federal Ministry for Economic Affairs and Energy (BMWi) in the area of hydropower continues to be the ecological compatibility of the power plants. In the area of ocean energy, projects of a demonstration nature are funded in order to be able to better exploit the existing potential of this technology in the future.

In the area of hydropower and ocean energy, the BMWi approved new funding for a total of five projects with a funding volume of around 2.3 million euros in 2015. At the same time, around 1.7 million euros flowed into already ongoing research projects.



TRITON platform with SCHOTTEL instream turbines

Selected funded projects

Flexible platforms with robust turbines

Concepts for tidal energy plants are being tested and optimised in prototype systems around the world. The 150 to 220 tons 1-megawatt class turbines commonly used up to now have a diameter of 13 to 20 metres and are firmly anchored to the seabed. Their manufacture, installation and maintenance are cost-intensive and time consuming. In the **TidalPower** project, coordinated by SCHOTTEL HYDRO, an innovative concept is being implemented that combines a small 62.5 kilowatt turbine with a half-submerged carrier platform. The cost per installed output is thus significantly reduced.

The turbine concept was developed by SCHOTTEL HYDRO. The SCHOTTEL Instream Turbine (SIT) has a diameter of just 4 metres and its design is simple and robust. The intelligent rotor blades deform when overloaded so that any increase in thrust is reduced. The idea for the new type of carrier platform came from the SCHOTTEL HYDRO subsidiary TidalStream. The TRITON platform is only anchored to a single fixed swivel joint on the seabed. This allows the platform to independently position itself depending on the tidal streams. The TRITON platform enables the turbines to be positioned at the optimal water depth – neither too near to the seabed, where there are slower water currents, nor too near to the water surface, where the current is disrupted by waves. The platform can be propelled to the water surface for maintenance by emptying the ballast tanks.

Other project partners are the University of Siegen, the Hamburg Ship Model Basin, the Potsdam Model Basin and the Fraunhofer Institute for Wind Energy and Energy System Technology IWES. The BMWi is funding this project with around 2.3 million euros.

Power plant technology and CO_2 capture and storage

Renewable energies should cover 80 percent of gross electricity consumption in Germany by 2050. Yet there is still a long way to go to achieve this target. Despite the constant expansion of environmentally friendly energy and efficiency technologies, the proportion of gross electricity production accounted for by lignite and hard coal is still over 40 percent and the proportion accounted for by gas is around 10 percent. Fossil fuels continue to play a significant role in the generation of electricity. The funding of research and development activities is an important factor for keeping conventional power plants fit for their ever changing role in the energy system.

Market developments in Germany and across the world

Although the contribution made by conventional energy sources to the German energy system is continuing to decrease, combined gas and steam power plants and coal-fired power plants have great significance for the security of supply and grid stability. Their role is currently facing a fundamental change in order to reflect the new systemic requirements. Nevertheless, fossil fuel-fired turbines will still represent a main pillar of Germany's electricity supply system until at least the middle of the century.

In the meantime, conventional power plants fulfil the important task of providing fast reserves to reliably compensate for the missing output (so-called residual load). This purpose will become increasingly important as the central focus point for every single power plant connected to the grid as fewer and fewer conventional power plants will have to regulate more and more renewable energy power plants. The fact that this has been achieved up to now without any supply disruptions demonstrates that the energy transition is well under way.

The global expansion of power plants utilising renewable energies is constantly increasing. Nevertheless, the global demand for conventional power plants, technologies and components "Made in Germany" continues. Therefore, exports have become a key sales focus for German manufacturers. German suppliers are technology leaders in many global markets – particularly in Asia. Despite the fact that the growth of the domestic market in Germany is declining,

new conventional gas or coal-fired power plants are still being implemented abroad. In this context, technologies from Germany hold a position of considerable importance insofar as German manufacturers are able to produce the world's most efficient power plants and thus also contribute to resource efficiency on a global scale.

Progress in research and development

Due to the energy transition and the increase in energy technologies with high fluctuating feed-in characteristics such as wind turbines or photovoltaic power plants, the flexibility of conventional power plants must be improved and they must be upgraded for cost- and resource-efficient partial and minimum load operation based on the intelligent supply of electricity. Quick start-up and shutdown speeds, the ability to utilise a variety of fuels and fuel flexible combustion systems are decisive prerequisites for this type of flexible and rapidly changing operation. For this to be achieved technologically and economically while still being environmentally friendly, research and development must deliver everything necessary to create the scientifically sound foundations.

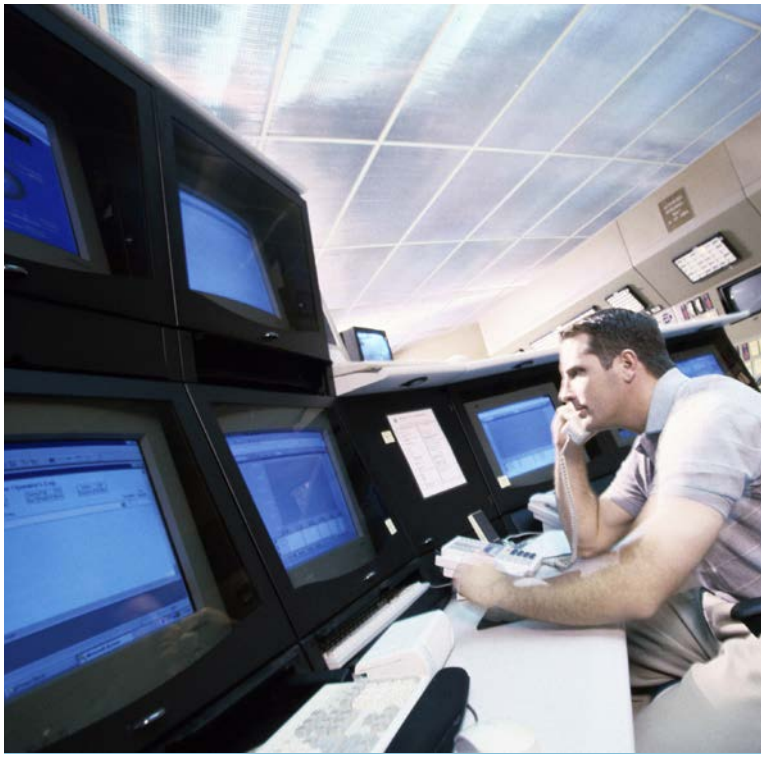
Major advances have already been made in the past few years in terms of the sparing use of fossil fuels and the reduction of CO_2 emissions. This has led to existing conventional power plants in Germany being continuously optimised. Modern lignite-fired power plants now achieve an efficiency of well above 43 percent, considerably reducing the use of resources. While these improvements in efficiency are extremely positive, the changing conditions nevertheless require new concepts and business models for the economic operation of fossil fuel-fired power plants as they will be limited to just a few thousand full load and partial load operating hours per year. One possibility in this area is to combine the thermal and material utilisation of fossil fuels (polygeneration).

In addition, research and development relating to the lifespan of power plants and their components must be intensified in order to optimise them for fast load changes. This is necessary to secure the energy supply in periods of calm wind, cloud or at night. It will require retrofitting or redevelopment to the changed conditions and to make it possible for gas and steam power plants to operate in very different and constantly changing modes permanently.

Alongside the German energy transition, the heating transition is also becoming a priority since the supply of cooling and heating account for more than half of the energy consumption in Germany. Efficiency measures and increasing the proportion of energy sourced from renewable energies are central issues in this area. Conventional power plants could make an important contribution by storing excess heat from thermal power plants.

In 2015, some important research projects were concluded. These included, for example, the **Clean Energy Center** project (for a description of the project, see the "Innovation Through Research" report for 2014, page 56). This joint project involved research and development work in 20 individual projects that will be implemented in the state-of-the-art Test Centre for Gas Turbine Burners. The centre was placed into operation in February 2015. Another successfully completed joint project was the "Partner steam power plant for the renewable generation of electricity" (also see page 56). The partners participating in the project have advanced the development of flexible, highly efficient thermal power plants through their work.

Conventional power plants must improve their operational flexibility



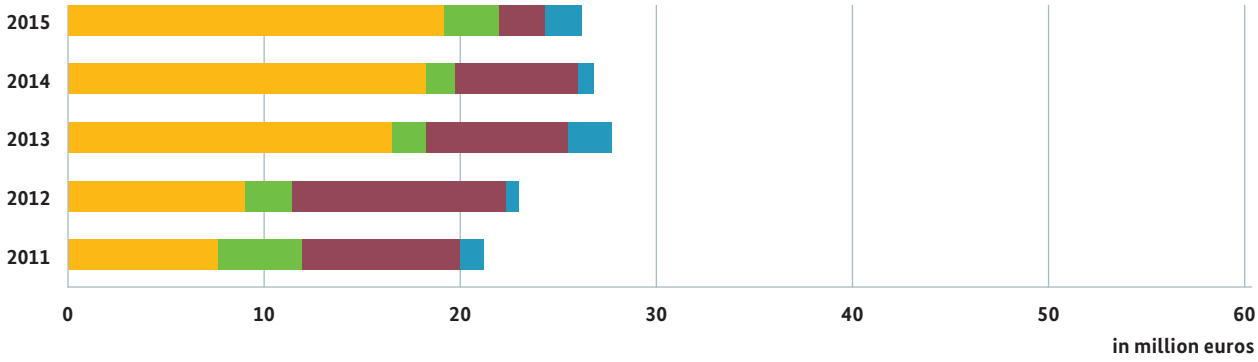
In the reporting year, important new projects were started that are focussing, amongst other things, on improving the flexibility of power plants. The **Grüne Erde** consortium (also see page 57) is investigating ways to utilise decentralised gas turbines for providing fast reserves of electricity. The **BGL Gasifier** research project (also see page 55) is a good example of a project dealing with the future-oriented theme of gasification technologies. This project is focussing on the further development of the British Gas Lurgi (BGL) gasification process that is also designed to support greater flexibility in conventional power plants.

Last but not least, research and development is making an important contribution to maintaining and improving the international competitiveness of German companies and research institutions and is thus playing a part in the creation of future-oriented and highly skilled employment opportunities in the area of power plant technologies in Germany.

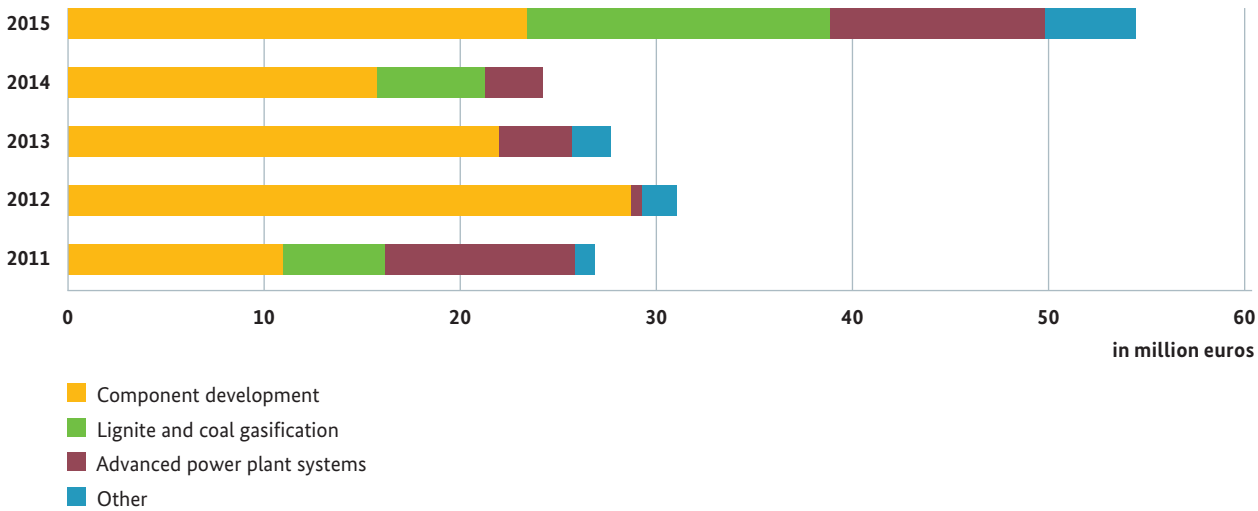
Strategy for the research funding

More intelligent, more flexible and cleaner: These are the main keywords for conventional power plants in the energy system of the future and thus also the goals of the German Federal Government in the 6th Energy Research Programme with respect to the further development of this conversion

Power plant technology and CCS: Distribution of funding between 2011 and 2015



Power plant technology and CCS: Trend in the volume of newly approved funding since 2011



IN FOCUS

Gasification technologies

The conversion of carbonaceous substances into combustible gases at high temperatures is called gasification. It enables the low-emission power generation and the environmentally friendly production of fuels and chemicals from coal. Prof. Dr.-Ing. Bernd Meyer is Head of the Institute of Energy Process Engineering and Chemical Engineering (IEC) at the Technische Universität Bergakademie Freiberg. One of the subjects he teaches and researches about is gasification technologies.

Prof. Dr.-Ing. Bernd Meyer, Technische Universität Bergakademie Freiberg

What are the advantages of gasification?
Meyer: The carbon is not burnt and converted into CO_2 but is instead converted into carbon monoxide and hydrogen using steam, the most important basic building blocks of organic synthesis chemistry.

Where do you see future application scenarios?
Meyer: In Germany, I believe – to put it pointedly – that synthesis gas generation is the only remaining long-term future for domestic lignite. Around 70 to 80 million tonnes of the approximately 170 million tons of lignite mined each year would be sufficient in theory to replace crude oil as the source material for organic base chemicals. I anticipate a renaissance in coal gasification in the next ten years, although in small steps. Two factors will play a role here: the development of crude oil prices and a reduction in investment costs.

Which technologies are the most promising?
Meyer: Gasification technologies that can efficiently convert low-grade coal into synthesis gas with the lowest amount of technical effort, as well as cost-effective and robust technologies. There are German technologies available that have been developed to industrial-scale maturity – fluidised bed gasification, entrained flow gasification, slagging gasification and fixed bed gasification.

How can economic efficiency be guaranteed?
Meyer: The most important approach by far is to reduce the investment costs for the entire synthesis process, primarily the generation of synthesis gas, which is the most expensive stage of the process. The greatest savings can be made if generation can be carried out in combination on-site in a power plant or chemical plant, i.e. when existing infrastructure can be used, such as a power plant boiler is available for the disposal of the gaseous, liquid and solid residues from the gasification process and gas purification. Here we are talking about polygeneration.

Where do you see a need for research?
Meyer: First and foremost in the implementation of the structural changes required by the German energy t ransition in the three German lignite regions of Lausitz, Central Germany and the Rhineland. I believe that the greatest need is to prepare for the 3rd generation of gasification technologies, which will meet the requirements for high efficiency, low emissions and the coupling of renewable energy via hydrogen and oxygen from the electrolysis process combined with a reduction in investment costs. Interdisciplinary basic research focussing on mathematical modelling seems to me to be particularly important. With respect to components, the priorities are optimising the drying process, the possibility of feeding in solid materials without an airlock and new gasifier and quench designs. Important at a system level is the integration of gasification into existing infrastructure and its functionality with minimal disruption and impact.

How would you evaluate the market opportunities?
Meyer: German companies are present on the international market and also competitive. The main competition is emerging in China and this makes the market situation difficult. Therefore, I can only advise industry to make the most of science for its comprehensive process and modelling knowledge. Incidentally, the next major forum for international discussion on technology and strategy is being organised by our Institute from 12 to 16 June 2016 in Cologne. It is the 8th International Freiberg Conference on gasification and synthesis gas technologies.

technology. The basis for the research funding from the BMWi into power plant technology and CO_2 separation and storage is the topic of the latest announcement (valid since December 2014) by the Ministry.

The main focus of the research funding from the BMWi is placed on research projects that have the aim of increasing the flexibility, efficiency and profitability of power plant processes or developing new materials and material technologies. In addition, the Ministry supports projects focussing on CCS technologies and other measures for reducing emissions. The BMWi also funds the development of new technological options, such as methanation processes (power to gas), oxyfuel and gasification systems or polygeneration, which is the combination of the thermal and material utilisation of fossil fuels. Another focus of the research funding is the integration of power plant processes into the system.

In the area of precompetitive, application-oriented project funding for power plant technologies and CO_2 separation and storage, the BMWi awarded a total of around 26.2 million euros in funding to 277 ongoing projects in 2015. In addition, the BMWi approved new funding for a total of 108 projects with a funding volume of around 54 million euros.

An important pillar of the funding policy of the German Federal Government is the COORETEC Initiative founded by the BMWi. It forms part of the Energy Research Programme and has provided specialist expertise for the further development of power plant technology in Germany for the past eleven years. On behalf of the Ministry, COORETEC identifies research and development needs and discusses and initiates ideas for new projects. The Initiative thus makes a contribution to securing an affordable supply of energy in Germany and to the positioning of German manufacturers in international competition.

Power plant turbine from Alstom

Selected funded projects

BGL gasification: Further developments towards IGCC and polygeneration processes

Gasifiers with liquid slag extraction based on the British Gas Lurgi (BGL) process are prominent due to their high cold gas efficiency for the conversion of solid fuels to gaseous and liquid hydrocarbons with low CO_2 emissions. With only minor technical modifications to the system, it is possible to significantly change the product range of the gasifier. This ranges from a very high proportion of combustible or synthesis gas through to a high taroil yield for applications in the area of polygeneration. Both process variants are interesting for the efficient and flexible supply of electricity.

A team at the Technische Universität Bergakademie Freiberg is conducting research to further the **development of BGL gasification into an IGCC and polygeneration gasification process**. The planned polygen-BGL concept is aimed at lignite- or coal-based plants for polygeneration with the creation of synthetic products, as well as the provision of storable peak load fuels (creosote).

The groundwork will be the completion of theoretical studies (including a model simulation). The scientists aim to subsequently carry out scientific experiments in the laboratory and in pilot plants. The site of an existing BGL gasifier is planned for this purpose. The combustible gas BGL concept aims to increase efficiency and reduce emissions. At the same time, the researchers aim to lower the complexity of the plants and also reduce the cost of IGCC power plants.

The project contributes to strengthening the innovative capabilities of German manufacturers of power plant components and improving their competitiveness. This development will also benefit the further expansion of electricity generation from renewable energy sources because it helps to make conventional power plants more flexible. The project received around 5 million euros of funding from the BMWi.

Plant for slagging gasification from the BGL Gasifier research project

HIGHLIGHT

Partner Steam Power Plant for the renewable generation of electricity

When there is insufficient sun and wind, fossil fuel fired power plants assume an important role for the uninterruptible supply of electricity. Previously, these types of steam power plants were designed for base and medium-load operation to cover around 4,500 to 7,500 full load operating hours per year. As a result of the increase in fluctuating renewable energies, power plants need to be upgraded to operate efficiently with fewer operating hours per year and lower minimum loads so that expensive start-up process and load changes that consume a lot of materials can be reduced.

In the **Partner Steam Power Plant** research project for the renewable generation of electricity, the **Rhein Ruhr Power** Cluster is working on the development of flexible, highly efficient thermal power plants. Elements such as high temperature storage systems, which were previously only installed in solar thermal power plants, were taken into account in the designs. This should enable the upgrading of lignite and hard coal power plants so that electricity from photovoltaic power plants and wind turbines can be fed-in as required in large volumes. The coordinator of this project, which comprised six subprojects, was the European technical association for power and heat generation – VGB PowerTech. Overall, seven research institutes and industrial companies participated in the project.

The scientists have investigated key technologies for making the "power plants of the future" more flexible within a sustainable, intelligent energy supply system and evaluated the economic efficiency based on the reference power plants Voerde (hard coal) and Schwarze Pumpe (lignite). The focus was placed here on improving the start-up process (saving time and money), reducing the minimum load (to 15 percent in Voerde, to 35 percent at the Schwarze Pumpe power plant) and increasing the load change speeds as important criteria for delivering more flexibility. Both technical and economic aspects were incorporated into the process. In addition, the partners have simulated and evaluated the thermodynamic behaviour of the power plant based on example power plants.

Although the focus was placed on existing power plants, the possibility of transferring the results to new constructions is being examined. Furthermore, approaches for integrating low and high temperature storage systems into conventional power plants on the basis of solid, liquid salt and steam storage systems were developed and then evaluated for their quality and thermodynamic restrictions. The findings showed that thermal energy storage systems integrated into high temperature steam areas and in the flue gas line were the most suitable based on their high level of performance.

The project, which was awarded funding of around 1 million euros by the BMWi, has advanced the feed-in of high proportions of electricity generated by volatile wind turbines and photovoltaic power plants through the flexible operation of conventional power plants.

Solar thermal power plant

Cogeneration plant (CHP) with a 6-megawatt class industrial gas turbine

Impact of associated substances in separated CO_2 flows on transport, injection and storage

The increasing concentrations of CO_2 in the atmosphere present a major challenge. CO_2 separation and permanent storage deep underground can contribute to a reduction in CO_2 emissions during the generation of electricity (in power plants) or in industrial sectors with process-related CO_2 emissions (e.g. steel and cement production).

The separated CO_2 contains – depending on the production process and the separation technology – different levels of associated substances such as SO_x, NO_x, H_2S, CO or O_2. These associated substances are the focus of the joint project called **CLUSTER**. The aim of the project is to develop criteria and recommendations for the definition of minimum composition thresholds (see Directive 2009/31/EC) which separated CO_2 flows must fulfil to be allowed to be fed into a common transport and storage infrastructure. Seven partners are participating in the project – two German government research institutes, three universities and two small or medium-sized companies. The project is being coordinated by the Federal Institute for Geosciences and Natural Resources (BGR).

The scientists are examining a representative regional cluster of different CO_2 sources as a model scenario. The aim is to combine the separated CO_2 flows from each source in one collection pipeline, transport it and inject it into a geological storage system. The main focus of the scientists is the impact of the changing composition of the collected CO_2 flows over time and the variable flow behaviour on transport, injection and storage. One example is the corrosive effect of the changing composition of the CO_2 flows on plant components, pipelines, steel, borehole cement and storage reservoir rock. The BMWi is funding the joint project with around 3.9 million euros.

Decentralised gas turbines for fast reserves of electricity

Fluctuating feed-ins from renewable energies make it necessary to provide fast power reserves. A promising approach could be to integrate industrial turbines into electricity generation because these can be started rapidly and thus secure the stability of the grid.

In the **Grüne Erde** project, a research consortium is aiming to increase the flexibility of electricity generation using decentralised gas turbines. The concrete aim is to develop a new industrial gas turbine in the performance class of 25 megawatts. The scientists intend to optimise it for use in combined gas and steam turbines and in cogeneration processes (CHP processes). The already fast reaction times of the turbines will be increased even further through improvement to the combustion chamber and the compressor.

The goal is to increase the thermal efficiency of small, compact gas and steam turbines by around 5 percent to 55 percent and the efficiency of the CHP process from 80 to 85 percent. In addition, the project aims to increase load flexibility and reduce the start-up time from 10 to 5 minutes. Furthermore, the consortium is striving to achieve single-digit ppm values for NO_x emissions at 40 to 100 percent load and to make the turbines flexible enough in terms of the fuel they use that they can utilise fuel that has had large volumes of renewably generated hydrogen added to it. This would allow natural gas – which is a source of CO_2 emissions – to be replaced by renewably generated H_2. Initially, the partners are carrying out this research on existing turbines with an output of 6 to 23 megawatts. The project is being coordinated by MAN Diesel & Turbo, while other participants are the Ruhr Universität Bochum and the German Aerospace Center (DLR). The project is being funded by the BMWi with around 3.1 million euros.

Fuel cell and hydrogen technologies

In the sector, fuel cells have long since made a name for themselves as clean suppliers of energy: They can directly generate environmentally friendly electricity and heat from oxygen and hydrogen without other external energy input, exhaust emissions, noise and wear – with the only waste product being water. Fuel cells are electrochemical generators of electricity that could also be described as gas-powered batteries. In future, this technology will assume a key role in the area of sustainable energy production.

Market developments in Germany and across the world

The mobility sector and the supply of household energy are two of the main ways in which fuel cell and hydrogen technology integrate renewable energies into the energy system. Large automobile companies have been working on fuel cell-powered cars since the beginning of the 1990s. In autumn 2015, the Japanese car manufacturer Toyota launched the first series production fuel cell car onto the German market with the Mirai and has thus taken the step into a new form of powertrains that could make petrol and diesel engines superfluous in the coming decades. "It will still be another ten, twenty or even more years until fuel cell cars make the breakthrough", warned even the company's Head of Development on the launch of the car onto the German market. The cost of fuel cell passenger cars has been considerably higher up to now than petrol or diesel vehicles and the network of hydrogen filling stations is not yet widespread: In Germany, there are currently 20 stations for fuel cell vehicles; the aim is to increase this network to 400 by 2023. The automobile manufacturers still hardly earn any money from hydrogen cars – although this situation could change in the long term. Mobility based on fuel cells should have captured a significant proportion of the market by 2050 and thus have made a noticeable contribution to the reduction of traffic emissions.

At present, around 1,000 fuel cells currently directly and efficiently supply environmentally friendly combined electricity and heat to households in Germany – now, the market must be comprehensively launched. The principle behind this technology is simple: Fuel cell heating systems have a connection to the natural gas grid and produce

hydrogen internally. The hydrogen reacts in the fuel cell with oxygen from the air to produce water and generate heat and electricity at the same time. The systems are highly energy efficient and thanks to their high overall efficiency of 90 percent they can deliver significant heating and electricity savings for supplying private households and also commercial enterprises with energy. The CO_2 emissions are reduced by up to 50 percent. As a decentralised generator of electricity, fuel cell heating systems can also reduce the load on the electricity grid or feed-in any excess electricity.

According to information from the German Association of Energy and Water Industries (BDEW), heating systems in German apartments and cellars are on average almost 18 years old and more than a third of these systems were even placed into operation before 1995 and are thus more than 20 years old. The goal of developers is that fuel cell heating should replace these outdated systems, as well as supplement existing heating systems.

At an international level, Japan continues to be the leading manufacturer; well over 120,000 fuel cell heating systems have already been installed through the state funded ENE-FARM programme. In order to remain competitive in the face of global competition and to achieve a market breakthrough in this area, the BMWi will be supporting stationary fuel cell heating systems with a new technology roll-out programme from 2016.

The fact that these systems, which have proven themselves to be durable and reliable in field tests after many years of research and development, are now commercially available is a success of the "National Hydrogen and Fuel Cell Technology Innovation Programme" (NIP) supported by the Federal Ministry for Economic Affairs and Energy (BMWi), the Federal Ministry of Transport and Digital Infrastructure (BMVI) and industry. The "Hydrogen Fuel Cell Initiative Germany" – an alliance of 13 partners from the world of politics, industry and science launched in 2015 – will also support the nationwide introduction of environmentally friendly hydrogen and fuel cell technologies.

Progress in research and development

The project funding provided by the BMWi in the area of fuel cell and hydrogen technologies was around 19.7 million euros in 2015 (2014: around 22.8 million euros) for a total of 119 projects. There were 42 newly approved projects with total funding of around 25.4 million euros (2014: around 21.5 million euros) over the entire lifetime of the projects.

A significant world record was set in 2015 by a solid oxide fuel cell: It reached 70,000 operating hours and has thus been running for eight years (see picture on page 58). This is longer than any fuel cell of this type has ever achieved before and proves that this technology is ready for deployment. The Jülich SOFC fuel cell (Solid Oxide Fuel Cell) only displayed a very low loss in performance due to ageing over the entire period (around 0.6 percent per 1.000 operating hours) – and new fuel cells are performing even better.

Due to their high efficiency, solid oxide fuel cells are ideal for supplying energy in the future to households and small business, as well as to large vehicles such as HGVs, trains and ships.

Innovations and modern energy technologies are the key to the energy supply system of the future. However, the expansion of renewable energies is not enough because wind and solar electricity are subject to large fluctuations. The restructuring of the energy system is thus only conceivable with suitable storage technologies – and this is where hydrogen comes into play, which is particularly suitable because it possesses a high energy density, is easy to store and can be efficiently converted back into electricity using fuel cells. So-called power-to-gas projects, which allow fuel cells to work in reverse as an electrolyser and thus convert renewable electricity into green hydrogen and oxygen currently form the second cornerstone for many manufacturers. The **EcoPtG**, **GreenH2**, **DruHEly** and **NestPel** projects are some examples in this area. The BMWi initiated these projects in 2015 and – in the area of fuel cell and hydrogen technologies – is thus increasingly promoting research and development into so-called electrolysers in addition to funding projects in the field of energy storage solutions.

Strategy for the research funding

Since the start of the "National Hydrogen and Fuel Cell Technology Innovation Programme" (NIP) in 2008, more than 200 research projects funded by the BMWi have been successfully completed. Despite the market launch of the first systems, research and development activities in this sector continue to be an important aspect for the

success of the German energy transition. This was also the consensus at the general meeting of the NIP in Berlin in 2015.

Fuel cell and hydrogen technologies are being developed further across the world and, alongside the automobile sector and supplying energy to households, other special applications (such as uninterruptible power supply systems) from further manufacturers are close to being launched onto the market. In order to keep pace with international competition in future, the challenge for the sector and for research and development is to develop a well-functioning supplier industry and infrastructure and to reduce costs further.

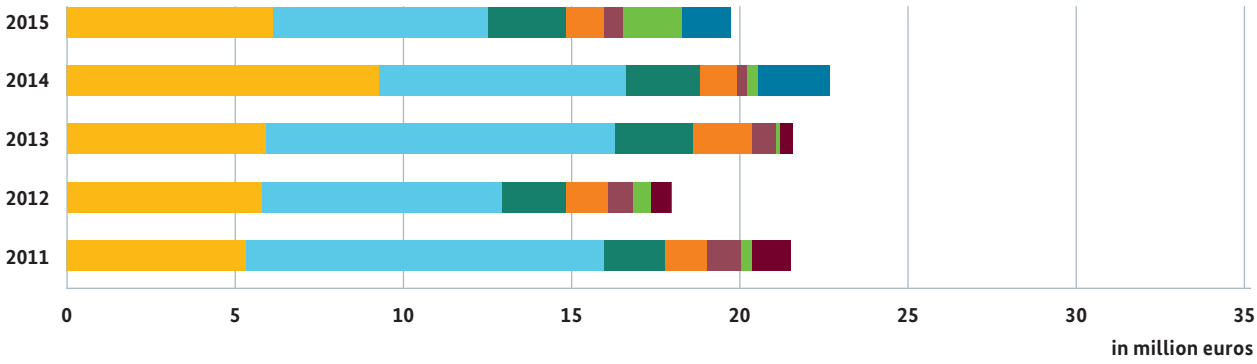
Selected funded projects

Hydrogen storage for mobile applications

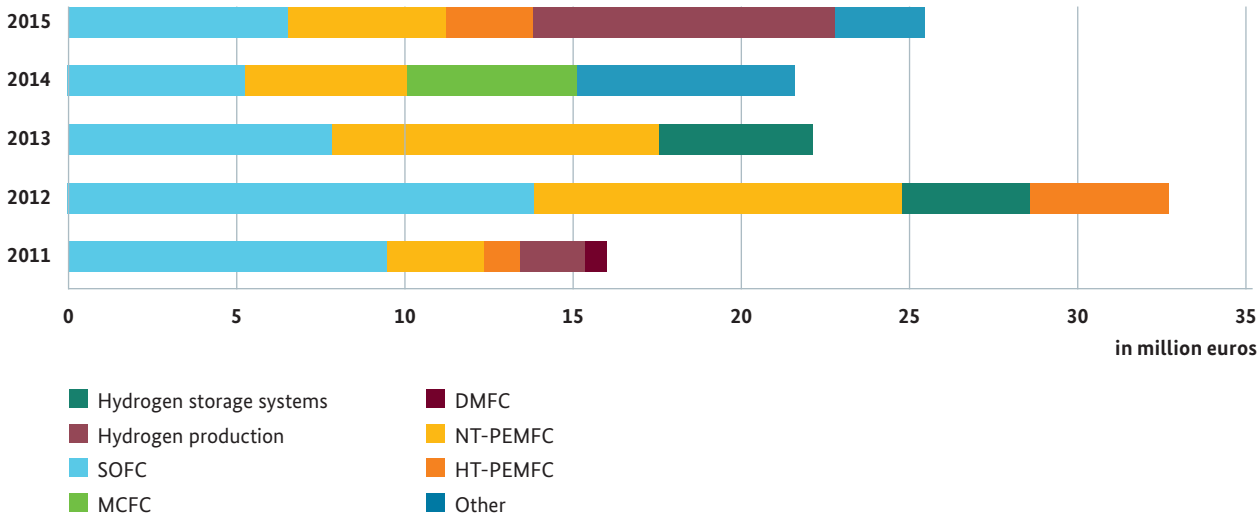
Mobile pressurised hydrogen storage systems are exposed to high levels of stress. They are required to store energy at a high density and at the same time be robust enough to tolerate high fluctuations in temperature and to withstand jolts and vibrations caused by the movement of vehicles.

In the **HyMod** project, six partners are developing methods for carrying out simulations of the thermomechanical design of pressure tanks for high pressure and cryopressure

Fuel cell and hydrogen technologies: Distribution of funding between 2011 and 2015



Fuel cell and hydrogen technologies: Trend in the volume of newly approved funding since 2011



IN FOCUS

Optimising the gas diffusion layer of fuel cells

In order to establish fuel cells as an alternative drive concept for vehicles, further development of their components is required. The OPTIGAA 2 project focuses on optimising the gas diffusion layer (GDL). Project Manager Achim Bock at Freudenberg, a technology company and GDL manufacturer, provides us with an insight into this research.

Achim Bock, Freudenberg

Mr. Bock, what makes the gas diffusion layer so important?
Bock: The GDL is an interface between the bipolar plate and the electrode in the centre of the fuel cell and it interacts with these neighbouring components. Its importance increases with the current density. The higher the current density, the more important the GDL because all transport processes are correlated through it. The more electricity is produced, the more gas is required and the more electricity flows through the GDL and the more heat and water is produced.

What is special about GDLs for vehicle applications?
Bock: As the current density for automobile applications is the highest, this is also the most challenging area of application. In the mobility sector, the long-term goal is to achieve ever higher current densities to increase the power density and economise on components. In this way, the individual cells and stacks will become increasingly smaller with the same performance. The necessary cost savings will result from the lower production costs due to economies of scale and process optimisations, as well as higher power densities so that less components need to be used to achieve the same output.

What are the goals of OPTIGAA 2?
Bock: Our goal is to understand what structures, raw materials and production processes are required to develop materials that are suitable for high power and current densities. This means examining the significance and relevance of the specific properties of materials for the gas diffusion layer and thus verifying the underlying FEM simulation model. Furthermore, it is important for us as a GDL manufacturer to know how we can influence and thus optimise the critical properties of the materials.

What progress have you achieved up to now?
Bock: In the first two years of the project, we defined and prioritised eleven criteria that represent in principle the entire concept of the GDL. In experiments, we then analysed how the individual materials could be changed to achieve significant improvements for these criteria. Our challenge now is to use the particularly effective individual materials to create material combinations that fulfil all eleven criteria at the same time and achieve the performance targets. The greatest challenge is dealing with the vast number of target variables at the same time because this makes the process very complex.

Where do you see a further need for research?
Bock: Interfaces are an important theme. It is not expedient in the long run for every manufacturer to optimise their individual components but instead everyone needs to cooperate on working on the interfaces between the different components. In addition, the manufacturing structures need to be developed further in order to produce GDLs more cheaply. Another aspect is automated quality assurance using inline testing processes that can replace the various offline processes that are both material and time intensive.

applications, as well as analyses and prognoses of their lifespan. This will act as the basis for the development of innovative hydrogen storage systems for vehicles. The coordinator of the project is BMW.

The development of the calculation method will be accompanied by corresponding experiments for the purposes of validation. The methods and simulation tools should form the basis for future development processes. The project aims to develop a standardised design, optimisation and safety method for assessing the impact of design and conceptual changes to the systems and components. In addition, the researchers want to reduce the scope of the cost and time intensive experimental investigations.

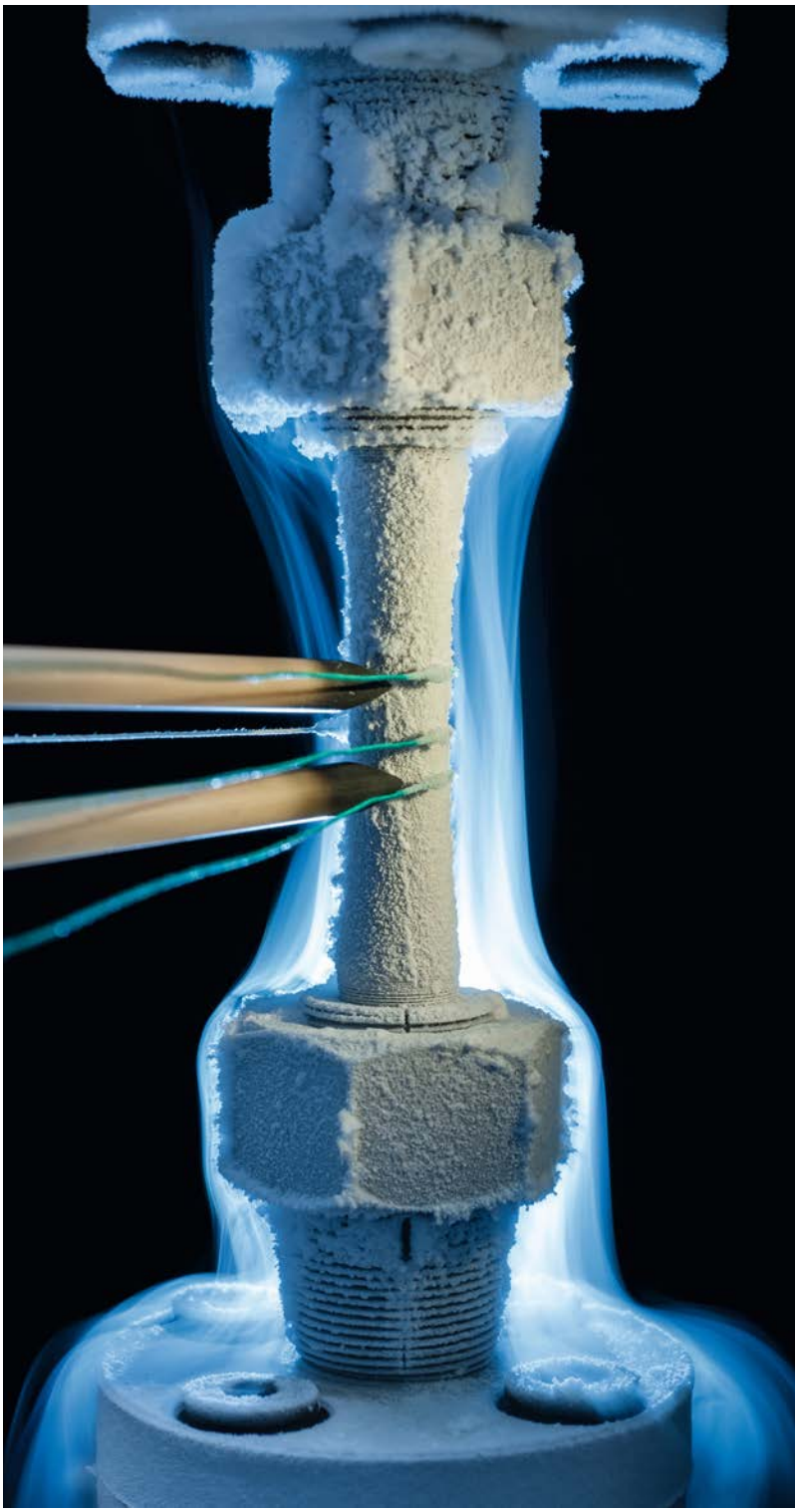
The project should thus contribute to a reduction in the overall runtime for future developments and their costs. Three industrial companies, two research institutes and one university are participating in the project. The BMWi is funding the joint project with around 4.5 million euros.

Another research project is **MatFuel**. This project, which is being funded by the BMWi with around 3.7 million euros, is investigating the influence of hydrogen on the properties of stainless steel and thus focuses on material technology for fuel cell components and hydrogen tanks.

Corrosion-resistant, ultra-thin, metal bipolar plates

In order to achieve sufficient performance, current fuel cell vehicle concepts utilise stacks of up to 400 cells. Therefore, the size, weight and cost of the bipolar plates contained in every cell are important factors for the marketability of this technology. They are traditionally produced from graphite or polymer composites containing graphite. Bipolar plates made from stainless steel are more stable and inevitably thinner, but the usual corrosion-resistant passivated layers have a high electrical resistance and thus reduce efficiency.

The aim of the **miniBIP** project is thus to develop corrosion-resistant, metal bipolar plates with new coatings of high performance materials. The project is being coordinated by the Fraunhofer Institute for Material and Beam Technology IWS and the Fraunhofer Institute for Surface Engineering and Thin Films IST. The main focus of the project is the creation of suitable material concepts and



Strain-controlled fatigue test at a cryogenic temperature of -196 degrees Celsius. The hollow sample is flooded here with liquid nitrogen

HIGHLIGHT

Fuel cell systems as environmentally friendly, off-grid electricity units

Off-grid auxiliary power units (APU) for the operation of small devices such as refrigerators or air conditioning units in delivery vehicles, mobile homes or yachts are only available on the market with the required electrical output of around three kilowatts as petrol or diesel powered units. However, their use is often limited by noise and emission regulations. Fuel cell systems have the advantage that they work at low levels of noise, emissions and vibrations and thus represent an attractive solution for the future.

A consortium coordinated by the OWI Oel-Waerme-Institut GmbH has carried out extensive research in this area. In the **MÖWE III** project, scientists are testing the technological maturity of a modular fuel cell system for use in future mobile applications. This diesel powered system was previously developed in the predecessor projects MÖWE I and II. It consists of a diesel tank, water tank, combustible gas generator and a fuel cell module with a low temperature PEM fuel cell (LT-PEM) with 90 cells, as well as a battery and corresponding power electronics. The autonomous system thus converts diesel into electrical energy and can achieve the required performance of 3 to 4 kilowatts for the intended applications.

MÖWE is based on a combination of diesel and SR PEM fuel cell technologies. The steam reforming process (SR) offers the highest hydrogen yield and the highest hydrogen partial pressure because there is no dilution with nitrogen.

The advantage of diesel is its high energy density, the already existing supply infrastructure and the fact that it is possible to store the fuel with no problems. The strengths of LT-PEM fuel cells lie in their long service life and short start-up times. In addition, these cells are already in series production.

The project partners achieved an important milestone on the path towards the market maturity of this modular system and the core goal of the third project phase with the conclusion of the project. The scientists were able to successfully demonstrate the functionality and technical maturity of the combustible gas generator, fuel cell stack and e-module. The team of researchers demonstrated its autonomous operation during multiple test cycles which included the load impact of an air conditioning system.

However, further research is required before the fuel cell system is ready for commercial application, in order to significantly reduce its size while delivering the same performance and not least to reduce costs. Alongside OWI ENASYS, the automation and management system supplier in-house engineering and the automobile supplier MAHLE Behr participated in the MÖWE III project. The BMWi funded the third phase with around 1.4 million euros.

Bipolar plates during surface treatment in the vacuum chamber

coating processes for the plates and the integration of test samples into low temperature PEM fuel cells.

The challenges addressed by the project were great. The goal of the scientists is to produce ultra-thin stainless steel plates whose coated surfaces possess the conductivity of the reference material gold without demonstrating any weakness in corrosion resistance in the acidic environment caused by the fuel cell reactions. The researchers have, on the one hand, investigated the formability of the material to ensure the optimal flow of the media based on new plate designs; while on the other hand, it was necessary to keep the composition of the surface modification as constant as possible over the entire lifespan of the fuel cell. The ultra-thin bipolar plates were ultimately set up and tested in a 50 cell demonstration stack. Finally, the project will focus on economic considerations. Outokumpu Nirosta and Daimler are participating in the project. The BMWi is funding this project with around 2.9 million euros.

Highly efficient catalysts for the desulphurisation of hydrogen

Hydrogen is considered a promising fuel source with numerous areas of application in both mobile and stationary scenarios. Catalysts are required for the decentralised extraction of hydrogen for fuel cells from natural gas. However, sulphur compounds contaminate catalysts and fuel cells and thus have an impact on the lifespan of the components and impede the functionality of the entire system. Therefore, a solution for desulphurisation is imperative for the commercial success of this energy system.

The **Catalysts for the decentralised generation of hydrogen and electricity for fuel cells** project from the company Clariant Produkte GmbH has been carried out in three phases and is researching concepts dealing with this technology. In the first two phases of the project, scientists developed new catalysts for use in fuel cells, as well as cheaper and more effective materials for removing the sulphur in the natural gas from the system and then subsequently tested them in field tests. Here, the researchers considered

HyProGen® catalysts for the decentralised production of hydrogen in fuel cells

all areas for the purification of hydrogen sources – from decentralised hydrogen generation through to waste gas purification.

In the currently funded third phase of the project, the scientists have developed a desulphurisation concept that also comprises logistics, the development of catalysts for steam reformation and new processes for their production. In addition, the concept will be supported by lifetime prognoses. The resulting findings should thus make an important contribution to the commercial success of fuel cell systems in Germany. The BMWi is funding the third phase with around 2.1 million euros.

Energy storage, electricity grids and the integration of renewable energies

One of the most important characteristics of the German energy transition is making generation and consumption more flexible. Accordingly, the future distribution and storage of energy must be based on the integration of electricity and heat from renewable energies. However, the infrastructure in Germany is not yet equipped sufficiently enough to deal with the constantly growing volume of fluctuating energy being fed into the system. In order to create the technical and system-based capacities, research and innovation into electricity and heat storage systems and new concepts, methods and materials for optimising the distribution grid are required.

Market developments in Germany and across the world

In contrast to conventional gas or coal-fired power plants, the electricity and heat generated by renewable energies fluctuates and is dependent on external factors such as the strength of the wind or the availability of sunlight. This means that excesses and shortfalls of renewable production can occur when the demand and supply of energy are not identical. As this is generally the case, the rapid distribution of energy and sufficient storage capacities are decisive for maintaining the stability of the grid without having to restrict the generation of electricity from renewable sources. Flexibility will thus be one of the most important characteristics of the energy system of the future.

There are a broad range of different highly developed technologies available for storing excess energy. In general, it is possible to differentiate here between thermal storage systems for supplying heat and electricity storage systems. The latter could contribute in the long term to the replacement of conventional power plants as they will be able to continuously store electricity or provide electrical output for the system.

While some applications are already well established, such as pumped storage hydro power plants or thermal storage heating systems, others are taking their first steps onto the market or still have a long way to go before they can be used in practice. The latter include, amongst others, thermochemical storage systems (also see “In Focus”, page 71). Amongst the storage technologies currently funded by the Federal

Ministry for Economic Affairs and Energy (BMWi), the most developed area is the market for photovoltaic (PV) home storage systems. In 2015, numerous suppliers launched new products onto the market that enable homeowners and business owners to store electricity from photovoltaic power plants on-site. There is however still a lack of reliable criteria for comparing these systems or a uniform method of certification to provide guidance to consumers. An important step in this direction is being developed in the **PV Nutzen** project (see also "The role of battery storage systems for PV systems connected to the grid for households and the grid", page 75). The scientists participating in the project have identified the economic, technical and ecological relevance of PV storage systems. In this context, a free calculator has been developed to assist consumers in selecting the right sized storage system for their household.

From a global market perspective, electrical energy storage systems have experienced rapid growth due to lower prices for battery systems, major industrial contracts and also specific funding programmes in individual countries. Storage system projects with a total volume of around 1.6 gigawatts were either in planning or construction worldwide at the end of 2015. The leading players on the market are currently the USA and Japan in terms of research, the completion of demonstration projects in the megawatt range and the implementation of new solutions. Regarding the status of battery research, Japan is currently noticeably ahead of Germany. Thanks to the extensive funding of projects, the domestic sector in Germany is also highly dynamic, however, not least due to the developments in battery technology in the area of electromobility (also see Chapter 12 "Key economic elements of electromobility", page 114) or major projects such as **M5BAT** in Aachen (also see the "Innovation Through Research" report for 2014, Highlight project, page 76). This joint project is developing a 5 megawatt battery storage system. Batteries used in storage technology can already reduce the burden on the electricity grid and cushion the effect of fluctuations. They could thus play an important role for the security of supply in the electricity grid of the future through the integration of a higher proportion of renewable energy into the system.

Alongside the comprehensive introduction of storage systems, technologies for the transmission and distribution of electrical energy and thus the expansion and restructuring of the electricity grid at all voltage levels are of central importance for the German energy transition. As a result of the phasing out of nuclear energy, the reduction in the number of conventional power plants and the expansion of renewable energies, there has not just been a shift in energy technology but also a spatial separation of electricity generation and consumption. In order to nevertheless maintain a stable supply of energy as the basis for growth, prosperity and economic strength, the grids must be able to adequately and dynamically respond to the changing conditions and thus become more intelligent.

This includes, for example, the task of transporting electricity from the wind turbines in the less populated North of the country to Southern Germany. Due to the fluctuating provision of electricity from wind turbines and PV power plants, the distribution grids must become more robust, flexible and also be able to respond quicker than was previously necessary.

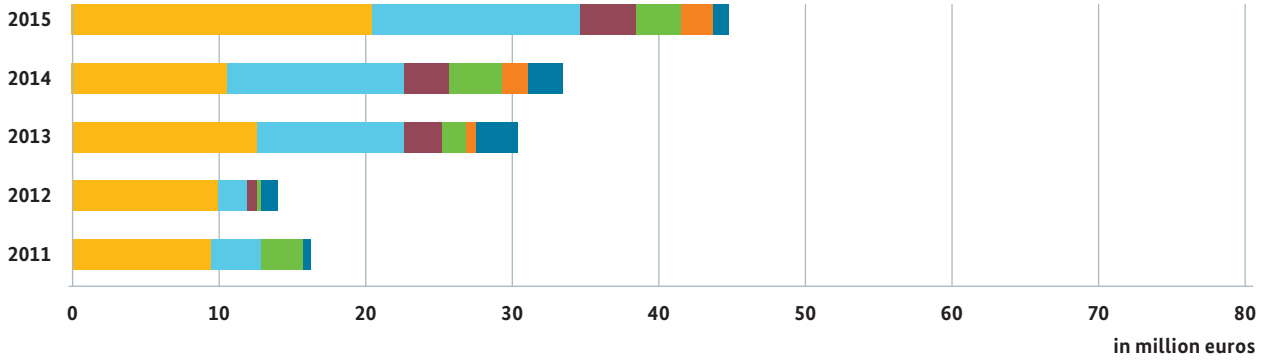
Solutions for the transmission and distribution grids are characterised by high levels of investment and long amortisation times. And due to the required planning and regulatory approval processes for individual measures, like the construction of new power lines, longer preparation periods must be planned for the realisation of new projects. The process from development to practical implementation thus takes longer than for other areas of the energy system. Nevertheless, one thing is clear: The nature of the grid infrastructure will change considerably in the next few decades and the necessary solutions will require ongoing research and development activities.

Progress in research and development

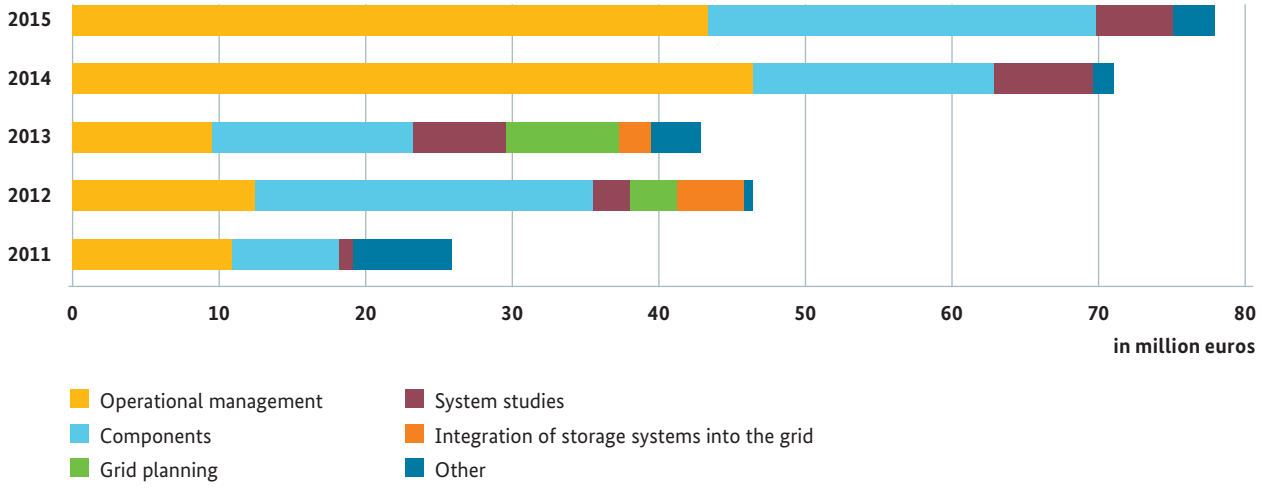
A comprehensive and uninterruptible supply of electricity is an important factor for the economy. Guaranteeing the secure supply of energy at all times is a significant requirement of the energy system in Germany and at the same time the driving force behind numerous research projects that focus on this overarching task. Some promising projects were started in this area in 2015.

If a large scale system failure should occur, it is essential that the grid can be promptly re-established. Previous concepts are now being put to the test by the energy transition because they were geared to an electricity system dominated by conventional power plants. In the **Netz:Kraft** project (also see "Highlight", page 79), the BMWi is funding the development of new solutions for re-establishing the grid that take into account the future structure with a high

Electricity grids: Distribution of funding between 2011 and 2015



Electricity grids: Trend in the volume of newly approved funding since 2011



proportion of renewable energies. Yet the infrastructure of the distribution grid itself – with which the security of supply can be improved by making the grids more flexible – is also the subject of research and development. The focus is placed here on the integration of suitable information and telecommunications technology. The joint project **Proactive Distribution Grid** (also see "Proactive distribution grid", page 78), for example, aims to upgrade the distribution grid to enable load and generation management across all voltage levels.

In the area of storage technologies, the focus is being placed on achieving market maturity. At the forefront of this research are cost, economic efficiency, performance and the manufacture of these systems in series production. The key is being able to develop solutions that fulfil all criteria at the same time. However, economic efficiency in particular is strongly dependent on the exact conditions of application so that it can generally not be determined across the board.

An important milestone in the development of innovative storage technologies was the commissioning of the largest hydrogen plant in the world with a PEM-electrolyser, the **Energiepark Mainz** (also see the "Innovation Through Research" report for 2014, Special Topic, page 74). This plant that was developed by the Stadtwerke Mainz AG, the companies Linde and Siemens and the RheinMain University of Applied Sciences, has been producing and storing hydrogen from renewable electricity since the summer of 2015. This hydrogen can then be stored on-site, pumped into trailers or fed directly into the natural gas grid to subsequently generate electricity and heat. The special feature: In contrast to other smaller pilot projects, the system can handle an input of up to 6 megawatts and supply 1,000 cubic metres of hydrogen per hour. It is thus capable of supplying, for example, 2,000 fuel cell powered cars and is unique worldwide. The Mainz Hydrogen Plant is a four-year pilot project that is being funded with almost 9 million euros by the BMWi. The economic operation of the plant will now be tested in the next few years.

In the area of system integration, the joint project **Flex4Energy** is focussing on the dynamics of the future energy system (also see "Highlight", page 86) and investigating the variability of storage systems, controllable loads and consumers. In this context, the project partners are developing a trading platform for delivering potential flexibility at a distribution grid level in order to be able to compensate for deviations between generation and consumption using flexibility options. However, the energy system of the future also depends on the ability to anticipate what volumes of electricity and heat will be required when and where and how much electricity and heat will be being generated when and where. This requires reliable forecasts. An important research project in this area is, for example, the joint **EWeLiNE** project (also see "In Focus", page 84) that is investigating the impact of the weather on the stability of the electricity grid. The scientists are developing forecasting tools for this purpose and want to integrate energy-related information into the calculations for the weather models.

Strategy for the research funding

The German Federal Government has created an important basis for the funding of new innovations for energy storage with the "Energy storage systems" research initiative. Overall, in cooperation with the Federal Ministry of Education and Research (BMBF) the BMWi has funded more than 280 research projects with this initiative. On 22 and 23 April 2015, the 2nd Status Seminar of the funding initiative was held in Berlin with 277 participants. Throughout the two days of the conference, 82 joint projects presented their scientific work in 16 specialist sessions and utilised this opportunity to draw some interim conclusions. Irrespective of the necessary technological developments, the event demonstrated that many of the participants believe that for the integration of the various storage solutions into the energy system the focus needs to be placed on the question of economic efficiency and the search for suitable business models.

As a follow-up to the funding initiative, the BMWi is continuing to fund research into energy storage systems as part of the currently open funding announcement from December 2014. The Ministry thus aims to push forward the further application-based development of these systems. This is because there is still the need for research and development in relation to the lifespan, number of charging cycles, costs and many other parameters. The funding awarded by the BMWi covers electrochemical storage systems, compressed air and flywheel mass storage systems and thermal storage systems, as well as overarching themes such as load management.

In the key funding area "Grids for the electricity supply of the future", the BMWi is funding innovations that will upgrade the electricity grid infrastructure so that high proportions of renewable energies can be integrated and at the same time guarantee a reliable and affordable supply of resource-efficient and environmentally friendly energy. The focus of the funding has been placed on energy efficient grid technologies, solutions for intelligent grid management and optimised grid planning. The integration of renewable energies into the system is closely related to the restructuring of the electricity grid. Accordingly, the BMWi is also supporting projects that target issues in this area.

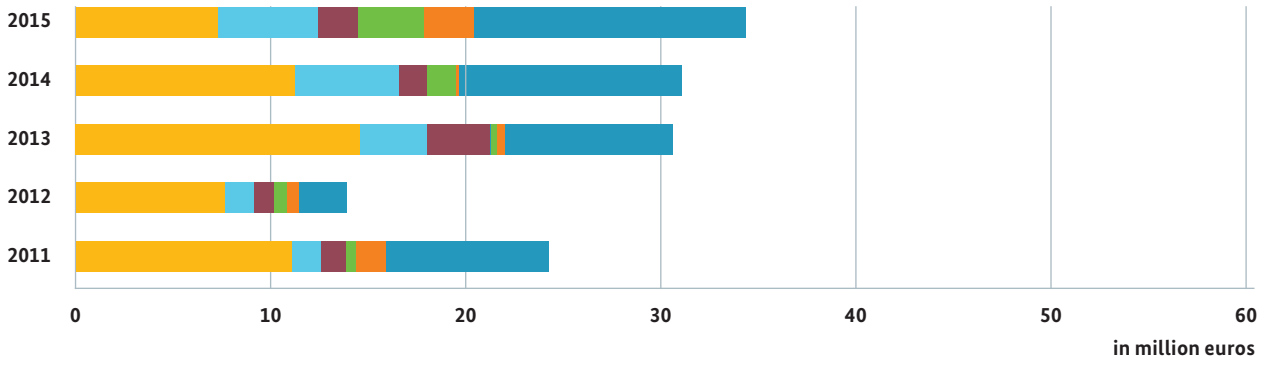
In addition, the BMWi is supporting research and development activities into new processes, concepts and materials within the "Future-proof power grids" funding initiative in cooperation with the BMBF. The first projects within the funding initiative started in August 2014. The ministries participating in the initiative are planning a status seminar for autumn 2016 that will include participants from all projects in order to discuss the initial results and take a look towards the future. This funding initiative encompasses a total of 312 research projects. The BMWi is funding 248 projects, while the BMBF is funding 64 projects. One of the joint research projects being funded by the BMWi is **Veredele**. The project is involved with regionalised distribution grids. The research team is focussing its work on the stability of control systems in distribution grids when operating with a high proportion of controllable, decentralised generators. The project is being coordinated by the Advanced System Technology (AST) Branch of Fraunhofer IOSB. The BMWi is supporting this project with 3.3 million euros.

The BMWi further underlined the importance of technological developments in power electronics with a call for applications for funding in this area. This call for applications has resulted in numerous project ideas (sketch). In the next stage, those companies, research institutes and universities that were successful in the project sketch phase can now make a formal application for funding from the Ministry. The first projects resulting from this call for applications should begin during the course of 2016.

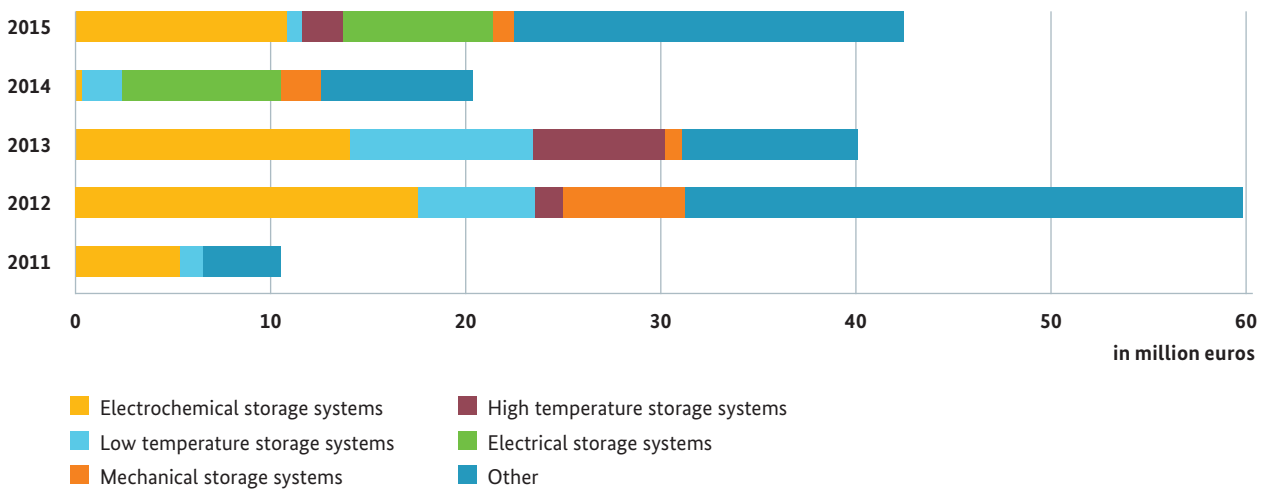
In parallel to this call for applications, the "Power Grids" research network was also founded on 12 May 2015. This network founded by the BMWi comprises around 130 members and aims to bring together scientists and representatives from industry, local authorities and politics in dialogue. The network is organised into a range of working groups, within which the participants can intensively exchange information and ideas dealing with research and development in the area of electricity grids. This cooperation should act as the basis for cross-project dialogue between scientists. In addition, the BMWi hopes to gain new insights that can be used at the appropriate point in the form of measures for funding research and development in the area of electricity grids.

In the area of energy storage, electricity grids and the integration of renewable energies, the BMWi approved new funding for a total of 221 projects with a funding volume of around 120.7 million euros in 2015 (2014: 209 new projects with a volume of around 106.4 million euros). The BMWi awarded 79.1 million euros (2014: around 73.4 million euros) of funding to 682 ongoing projects.

Energy storage: Distribution of funding between 2011 and 2015



Energy storage: Trend in the volume of newly approved funding since 2011



Energy storage

IN FOCUS

Thermochemical storage systems for providing heating and cooling

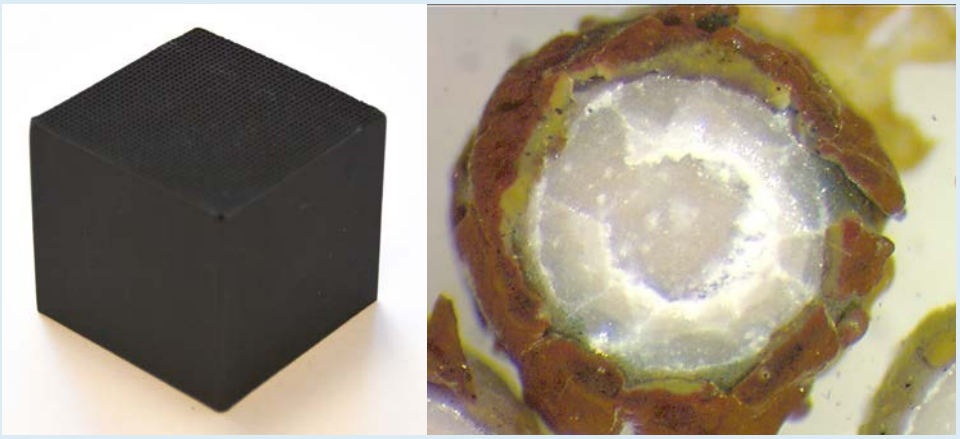
Alongside the storage of electricity, the provision of heat and cold is also necessary. This is because heat production accounts for the largest proportion of overall energy consumption. In order to guarantee a reliable and inexpensive supply throughout the year to buildings and districts in future, thermochemical storage systems are a promising option.

Thermochemical storage systems utilise sorption processes or reversible chemical reactions. They offer the potential of decoupling supply and demand due to loss-free storage. In addition, they possess a very high theoretical storage density and can adapt the temperature level when charging and discharging to requirements. Thermochemical storage systems thus play an important role for the security of supply and the transportation of heat. In order to make these systems technically and economically fit for practical use, the BMWi is funding a wide range of different research projects.

One of the thermochemical storage projects funded by the BMWi is **HyAktiv**. In this project, scientists at the Fraunhofer Institute for Solar Energy Systems ISE in cooperation with DINEX, a manufacturer of waste gas and emission systems, are carrying out research into the production of activated carbon from renewable raw materials and the hydrophilisation of these forms of activated carbon to improve the performance of adsorption storage systems. The project team are placing their focus on the optimisation and adaptation of the sorption characteristics to the specific application conditions in a heat storage system. The BMWi is funding this project with around 880,000 euros.

In the **BERTI** project, scientists at the Institute of Engineering Thermodynamics at the German Aerospace Center (DLR), in cooperation with the University of Siegen, are carrying out research into chemical heat storage systems using quick lime (calcium oxide, CaO). The project focuses on the movement of the storage material and the development of efficient control of the processes and reactions. The aim is to be able to configure the thermal capacity and the heat output independently of one another with the aid of a moving reaction bed.

The researchers also want to use the project to prove that the reactants can be stored separately from one another and thus without any losses. As a result of the separate addition of the solid materials into the reactor, it should be possible to separate the thermal capacity from the thermal output in order to achieve cost reductions for storage. The BMWi is funding BERTI with around 1.1 million euros.



Activated carbon from the HyAktiv research project (left)

Capsulated storage material from the BERTI research project

The distribution of liquids in the absorber module

Selected funded projects

Liquid sorption storage systems for cooling, heating and drying processes

Sorption heat storage systems have high energy densities and enable almost loss-free storage over a long period of time. In the **SorpStor** project, the Stuttgart University of Applied Sciences has utilised this principle to develop an open, air driven, thermochemical liquid sorption storage system for cooling, heating and drying applications that can be fed using waste process heat or solar thermal energy. In addition, the scientists at the university in cooperation with their project partner Wolf, a manufacturer of energy saving systems, are investigating a variety of inorganic and organic salt solutions for their potential to store energy. The development of charging and discharging strategies for the liquid sorption storage system was also a key question for the researchers because this is decisive for the efficient retention of the heat.

Based on laboratory experiments on the sorbents and analyses of the storage densities and processes, prototypes were developed consisting of a regenerator, absorber and liquid sorption storage system. The performance tests carried out on these individual modules and a collector module were then used by the scientists to build complete systems with liquid sorption storage units with charging and discharging strategies for the storage of thermal drive energy over hours, days or weeks. A cost-benefit analysis and an economic assessment of the complete system were completed in parallel.

The consortium aims to develop the storage system to market maturity by 2017. In addition, the aim is make it possible in future to integrate the system into existing air conditioning and heating devices available on the market. The BMWi is funding this project within the "Energy storage systems" research initiative with around 630,000 euros.

Thermochemical long-term heat storage system for the heating of residential houses

The advantage of thermochemical heat storage systems (sorption storage systems) is their high and almost loss-free specific storage capacity. They could thus form an important basis for the year-round supply of heating from renewable energies.

In the **EnErChem** project, the University of Stuttgart and its three partners developed and tested a thermochemical sorption storage system for heating houses and apartment blocks. This system stores heat with the aid of zeolite balls. Therefore, extensive work into new, highly efficient storage

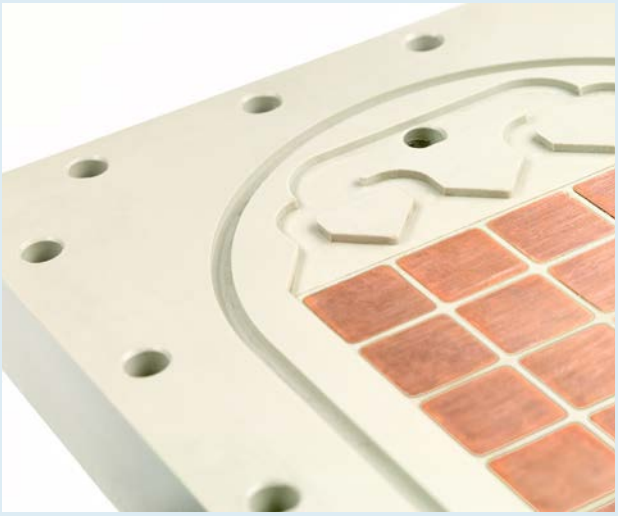
HIGHLIGHT

Further development of zinc-air energy storage systems with a high current density

Zinc-air energy storage systems possess many advantages for stationary applications. The high specific energy content, low cost of the activated materials, high availability of zinc, a high level of technical safety and the good environmental compatibility of the materials could lead to an optimal storage technology if fully exploited. There are still some challenges to overcome on the way to this goal. For example, the number of charge and discharge cycles that could be achieved until now at technically relevant current densities is unsatisfactory, while the energy efficiency of the cells used must also be improved.

Covestro Deutschland (previously Bayer MaterialScience) and Grillo Werke AG in cooperation with the Clausthal University of Technology, the University of Duisburg-Essen, the Fuel Cell Research Centre ZBT, the University of Saarland and the Niederrhein University of Applied Sciences are investigating various aspects of zinc(Zn)-air technology in the joint project **ZnPlus** to develop a competitive cell design that can be scaled-up to the megawatt range. In this context, the project partners have constructed and evaluated a variety of Zn-air cells and built a modular cell system that could be used to characterise different operating concepts through replaceable components. Advantageous materials for the discharging and charging collectors were determined, the passivation of solid Zn electrodes investigated in detail and optimal operating parameters identified for discharging the cells.

Segmented cells



The oxygen depolarized cathode (ODC) developed by Covestro for the chloralkali electrolysis process proved itself to be technically robust for the tested Zn-air cells. When comparing cells with solid Zn anodes on the one hand and flowing Zn slurry with a separated collector on the other, it was demonstrated that current densities of up to 4 kA/m² could be achieved with the slurry anode. Different compositions of the zinc slurry electrode were then tested and thus a strong correlation between the performance of the batteries and the composition of the electrode was determined.

Further optimisation of the performance of the preferred Zn slurry cell was carried out by investigating the formulation of the slurry. This involved the completion of a statistical testing plan comprising 120 slurry formulations, resulting in the identification of promising formulations for increasing the stability and dischargeability of the slurry. In parallel, the complex flow behaviour of the slurry was numerically and analytically examined to identify the correlation between cell performance and flow conditions and thus find optimised operating conditions.

Future development work will focus on optimising costs and long-term testing of the Zn slurry cell. In a follow-up project, the aim is to construct a robust multi-cell model and validate it under conditions close to real-life application. The BMWi funded the research into ZnPlus with around 2.5 million euros. The project is part of the “Energy storage systems” research initiative of the German Federal Government.

Salt-impregnated zeolites from the EnErChem research project

materials based on zeolites and salts was a key area of the project. In terms of their thermochemical properties, composites consisting of calcium-exchanged zeolite 13XBFK and calcium chloride proved especially promising. Overall, the researchers were able to significantly improve the energy storage density of the materials. In addition, the project also focussed on developing a concept for an external and thus independently scalable reactor and the development of industrial production methods for the materials.

In a demonstration plant, the researchers finally technically implemented the developed process concept and tested the thermochemical energy storage system as part of a heating plant under real conditions. The scientists investigated the suitability of the system for use as a seasonal heat storage system for solarthermal power plants and as a storage system for CHP and photovoltaic power plants. The University of Leipzig, Vaillant and Chemiewerk Bad Köstritz have participated in the joint project. The BMWi supported the project within the "Energy storage systems" research initiative with around 1.8 million euros of funding.

Making PV power plants with electrical storage systems safe and reliable

Photovoltaic power plants will be increasingly combined with electricity storage systems in the future. This will also bring safety issues to the forefront of considerations with regards to these types of installations.

In the joint project **SPEISI**, scientists are carrying out research into the safety and reliability of PV power plants with storage systems, placing a special focus on fire risks and extinguishing strategies. The project is based on a predecessor project that evaluated the fire risk posed by PV power plants and within which a safety concept and guidelines for minimising the risks were developed. The project is being coordinated by the TÜV Rheinland.

The main focus is the analysis of risks that arise in different scenarios when damage is caused to household electricity storage systems used with PV power plants. In the process, the scientists aim to identify possible weaknesses, such as in the rules of application, handling, installation and operation. Furthermore, the partners are investigating strategies for emergency and rescue personnel when handling storage systems in an emergency. The main focus here is placed on the possible risk of fire and suitable extinguishing strategies. In addition, the researchers want to develop criteria for determining the performance of photovoltaic storage systems.

The Fraunhofer Institute for Solar Energy Systems ISE, the German Solar Energy Society and the Center for Solar Energy and Hydrogen Research are participating in this joint project with the TÜV Rheinland. The BMWi is funding this joint project with around 3.8 million euros.

The role of battery storage systems for PV systems connected to the grid for households and the grid

As a result of the increasing attractiveness of own consumption from PV power plants due to the rise in electricity costs, greater focus is being placed on home energy storage systems. The question then turns to the effect of storage systems on the electricity grid and the optimal size of storage units for individual households. This subject was investigated by the ISEA and IFHT institutes at the RWTH Aachen University and the Institute of Ecological Economic Research (IÖW) in the **PV Nutzen** research project.

The scientists observed the role of battery storage systems in households with photovoltaic power plants attached to the grid and worked on identifying the commercial, economic, technical and ecological benefits of these storage systems. An important finding from the project was that the burden on the grid could be reduced through a combination of a photovoltaic power plant and battery storage system for own consumption with the aid of so-called persistence forecasts and the intelligent programming of the storage system. This would make it possible to significantly reduce short-term peaks in the feed-in of electricity as a result.

In this project, a free PV storage system calculator is also being developed to calculate the ideal size of home storage systems. This tool can be utilised to calculate the economic efficiency of a selected system and also the ratio of own consumption. All of the parameters such as the price of the electricity and the batteries or the feed-in tariffs are entered into the calculation and if desired the user can adapt them to their individual situation. The BMWi has funded the PV-Nutzen project within the “Energy storage systems” research initiative with 870,000 euros.

The scientist of PV Nutzen developed a free PV storage system calculator to determine the ideal size of the home storage unit

Power grids

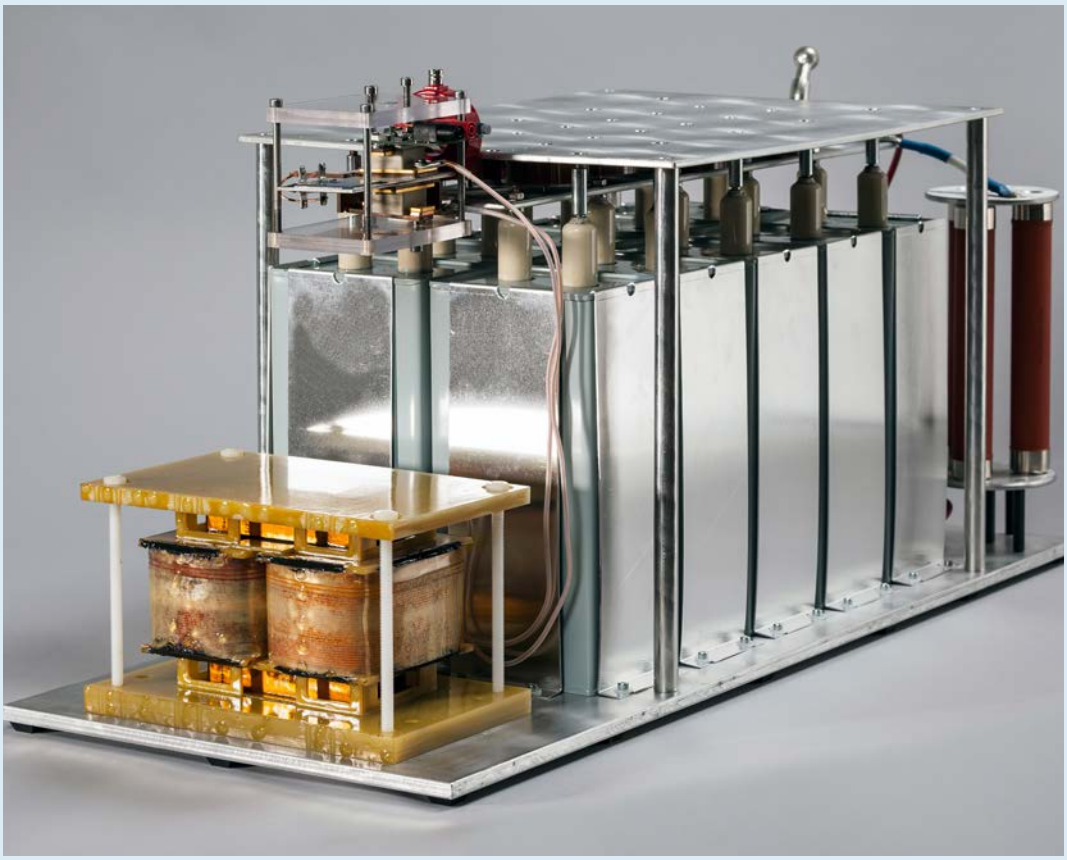
IN FOCUS

Power electronics for electricity grids

An important component of modern energy transmission and distribution is power electronics. The Federal Ministry for Economic Affairs and Energy issued a call for applications for funding early in 2015 in order to stimulate further research and development projects in this field. The BMWi is already funding a variety of research projects on power electronics within the 6th Energy Research Programme.

One of these projects is **SiC-BiNet**. The project, which is being supported by the BMWi with around 1.5 million euros of funding, is conducting research into bidirectional medium voltage converters with high voltage SiC construction elements. This research aims to improve and increase the integration of renewable energies and inner-city storage systems into innovative grid structures. The goal of the project is to develop a demonstration unit for a highly compact, single-phase bidirectional AC/DC convertor with high voltage silicon carbide construction elements. The output of the demonstration unit should be around 100 kilovolt-amps with an efficiency of over 96 percent. Following the completion of the project, the results will be transferred to different applications (AC+DC grid connections, integration of storage systems in the 20 kilovolt grid and the integration of renewable power plants into the 15 kilovolt train power line network) and conclusions drawn about its suitability for these different types of application. The project has three partners and is coordinated by the Fraunhofer Institute for Solar Energy Systems ISE.

The photo shows a test set-up for measuring the SiC transistors



Another project conducting research into power electronics is **NET-Control**, which is being funded by the BMWi as part of the "Future-proof power grids" research initiative with around 1.1 million euros. This joint project with four partners is being coordinated by KSB, a manufacturer of hydromechatronic systems. In the project, scientists want to develop innovative power electronics for the grid-stabilising effect of hydromechatronic processing plants. These should not only contribute to the stabilisation of the grid but should also increase grid efficiency. The aim is to develop a stand-alone standard solution for an intelligent power electronics system with integrated data communications. Real-time control algorithms will be used to specifically set the active and idle power consumption of a whole system of (large) electrical consumers in production or supply technology. It is these users of large amounts of electricity, in particular, who have a significant need for highly dynamic grid services. The main focus of the work is being placed on grid operation management, flexible consumption, load management, decentralised automation concepts and intelligent subsystems. The researchers want to test the developed strategies, components and algorithms on the actual example of a drinking water supply system.

Pump meter from the NET-Control project

Selected funded projects

Regionalisation of the energy supply system at a distribution grid level

Renewable energies are fed into the system decentrally. In order to limit the expansion of long-distance electricity transmission lines, new approaches at a local authority level are required for the local conversion, storage and utilisation of energy.

Scientists in the **REgEnKibo** project are carrying out research into the regionalisation of the energy supply system at a distribution grid level at a pilot site in Kirchheimbolanden in Rheinland Pfalz. The researchers aim to model the town's electricity and gas grids, validate the model with the aid of real-time data and then combine this information to develop intelligent grid technology and infrastructure for the regional supply of energy. The need to balance electrical energy between the transmission grid and the distribution grid will be reduced to a minimum and thus help to minimise grid expansion. In addition, the project partners hope to achieve savings for private households, the public sector and business through energy efficient electricity and energy systems optimised for heating that can further reduce the exchange of balancing energy.

The BMWi is funding this project that is coordinated by the energy supplier e-rp GmbH with around 2.1 million euros as part of the "Future-proof power grids" research initiative. Other partners are the Karlsruhe Institute of Technology (KIT), the University of Bingen, the Deutscher Verein des Gas- und Wasserfaches e.V. (DVGW) and the Viessmann Group.

Proactive distribution grid

The increase in the fluctuating levels of decentralised energy fed into the low, medium and high voltage grids is increasingly influencing the behaviour of the system and is starting to demand a more active role of distribution grid operators. As a result, there is a greater need for information, control and management options.

The research consortium **Proactive distribution grid** of RWE is focussing on the development and demonstration of a resource-efficient and optimised distribution grid platform for integrating renewable energies and smart market tasks. The partners involved in the project aim to utilise a comprehensive, status-based load, generation and information management system across all voltage levels. It will take into account all market requirements and thus enable the optimised interaction of smart grids with the smart market. As the foundation for interaction between grid and market players, this concept is based on the traffic light

The regionalisation of the energy supply system limits the need to expand electricity transmission lines

HIGHLIGHT

Renewable energies supporting the expansion of the grid

The German energy transition is changing the requirements for system services offered by grid operators and the connected generating and consumption systems. One of these services is to re-establish the grid after a complete or widespread power failure. The existing concepts now need to be adapted to a power plant structure that has a high proportion of renewable energy power plants.

The **Netz:Kraft** project focuses on the re-establishment of the grid taking future power plant structures into account. In this project coordinated by the Fraunhofer Institute for Wind Energy and Energy System Technology IWES Kassel, the researchers want to further develop existing concepts of the transmission grid operators and in doing so integrate renewable energy power plants to a greater extent than previously. In addition, they want to investigate how so-called supply islands can actively support the re-establishment of the grid.

Normally, thermal power plants require large volumes of electrical energy from the surrounding transmission grid. It is only once they have been ramped up that they can provide electricity for their own consumption and for public supply. Following a widespread power failure, the transmission grid operators instead start-up power plants that have so-called black start capabilities. These are power plants that can be independently placed into operation without an external supply of electricity.

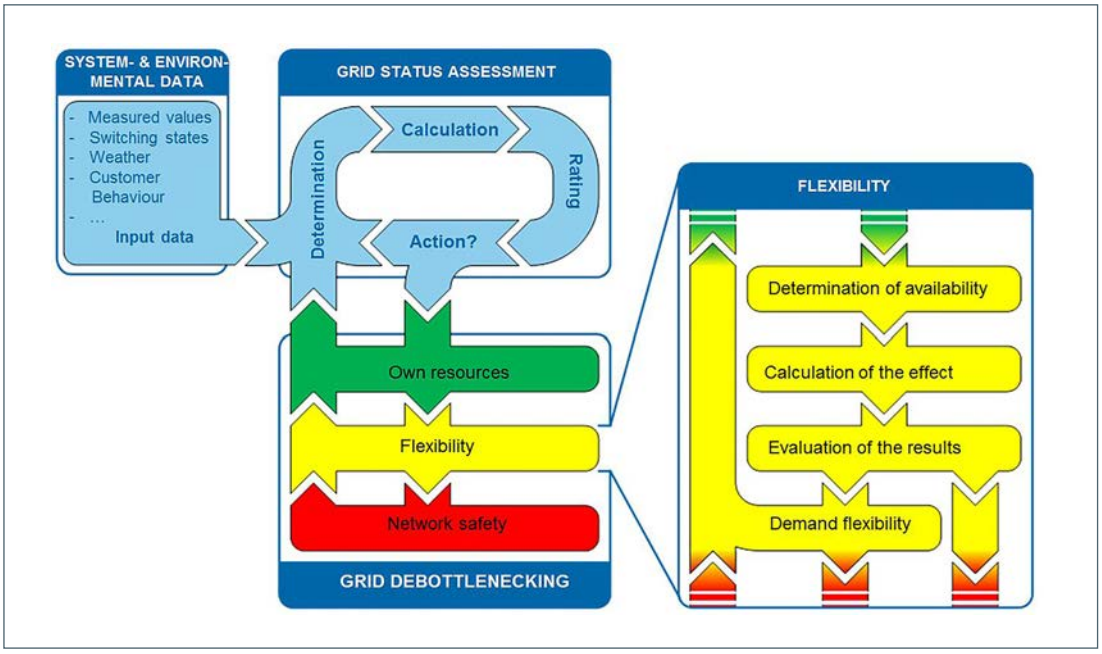
In order to re-establish the grid successfully, the status of the grid must be assessed. However, the increase in the number of decentralised renewable energy power plants at all voltage levels makes this process more complicated. The project partners are thus expanding the current concepts by considering the behaviour of renewable energy power plants when they are restarted to a greater extent.

In this context, they are also investigating the application, availability and interaction of information and communication systems in the event of a blackout. Furthermore, the researchers are determining the extent to which wind farms and solar parks as well as the HDVC grid can actively contribute to the re-establishment of the grid. The BMWi is funding this project with around 8.1 million euros as part of the “Future-proof power grids” research initiative. The twelve project partners comprise grid operators, manufacturers, consultancy firms and research institutes.

In the **LINDA** project, researchers are developing a concept to enable the stable operation of an isolated grid that can be scaled-up over several voltage levels in the distribution grid. In the case of long-term blackouts, the aim is for decentralised, electricity generation plants with black start capabilities to provide emergency supplies for critical infrastructure including hospitals, water supply and disposal systems or key transformer stations within locally isolated grids. Due to the volatile behaviour of decentralised renewable power plants, the control system for the isolated grid needs to be particularly robust and thus function without any communication connections with the power plants.

The functionality of the concept is being tested by the scientists at a number of test field sites within the distribution grid. Eight project partners are cooperating in this project that is being coordinated by the company LEW Verteilnetz GmbH. The BMWi is funding LINDA as part of the “Future-proof power grids” research initiative with around 1.3 million euros.

Diagram showing the proactive distribution grid



flexibility model, which will be developed and demonstrated in particular in the area of technical processes and components. The overarching goal of the project is to develop an open, non-discriminatory, standardised and transferable system for the electricity supply grid.

As a result, the researchers hope to exploit the existing capacities to the greatest possible extent with the best possible level of operational reliability and lowest expansion costs. The active role of the distribution grid will primarily include the collection and analysis of information on states experienced by the grid that are still widely unknown. Building on this information, the market and grid players will be coordinated depending on the relevant situation to minimise the number of direct interventions in the grid and optimally utilise the existing flexibility of the distribution grid. This will enable system services to be provided from the grid and for the partial automation of the management of the grid. Overall, six partners are participating in the project. The project is part of the "Future-proof power grids" research initiative of the German Federal Government. The BMWi is funding this research with around 2.1 million euros.

Intelligent automation of the distribution grid

Conventional expansion of the grid is costly, while the planning and implementation takes a long period of time. This means that alternative solutions are required long-term to satisfy the demands faced from the increased use of renewable energies.

In the **Green Access** project, engineers and scientists are developing concepts for automating the distribution grid across different voltage levels in the sense of a plug & automate system. A consortium of ten partners is working on the project. The energy supplier EWE based in Oldenburg is coordinating the project.

The goal is to develop and test an adaptive smart grid automation concept for medium and low voltage grids. The research approach is based on the "plug & automate" principle: The grid and control components should thus be made capable of automatically communicating with one another. In addition, the team is working on improved, adaptive monitoring and control algorithms, intelligent management systems and grid-based operating components. It should thus be possible to make the distribution grid run independently and in a self-learning manner so that it can adapt itself to future changes in load and feed-in volumes, changes in operating state and in the grid topology. In addition, the aim is to reduce the initialisation and

The project partners of Green Access at the kick-off event: EWE, EWE NETZ, BTC, EWE-Research Centre for Energy Technology – NEXT ENERGY, OFFIS – Institute for Information technology, Bilfinger Mauell, SAG, SMA Solar Technology, the University of Wuppertal and the Fraunhofer Institute for Solar Energy Systems

configuration work for grid and control components to a minimum. The researchers are dedicating themselves to answering the question of how intelligent distribution grids need to be in the future and what level of automation and networking is economically conceivable. Their findings will be checked in field tests. The project thus aims to make a contribution to making the future grid infrastructure technically and economically efficient. The BMWi is funding the project as part of the "Future-proof power grids" research initiative with around 4.1 million euros.

Dynamic control rooms for intelligently transporting electricity

The expansion of the grid will play a key role in the integration of renewable energies into the German energy supply system. This places changing demands on the transmission of energy and will require new grid monitoring and control strategies.

The **DynaGridCenter** project is investigating how conventional transmission grid control centres can be upgraded to make them into future-proof, dynamic control rooms to enable the intelligent transmission of electricity. This project, coordinated by Siemens, is carrying out research into the prerequisites for the future transmission grid control rooms, developing a dynamic grid management system demonstrator for the reliable operation of AC/DC transmission grids and testing it together with its new functions. The demonstrator is a distributed system consisting of an interactive grid simulator on the premises of the Otto von Guericke University of Magdeburg, which is monitored and controlled by the dynamic control room on the premises of the Ilmenau University of Technology.

The research work is focussing on the observation, recognition and management of dynamic phenomena in complex electricity grids such as the high and extra high-voltage grids in Germany. In order to observe these kinds of processes, it is necessary to be able to take fast and chronologically synchronous measurements. This leads to immense data flow that can no longer be interpreted in the control rooms without assistance. Therefore, the data must be evaluated automatically in order to make correct assessments of the security of the grid. In the dynamic control room, adaptive measures can be initiated that are precisely adapted to the current status of the system. The project results should lead to the ability to optimally manage the increased dynamics of the grid and also guarantee the familiar security of supply even in the future. Alongside Siemens, five universities and research institutions are also participating in the project. The BMWi is funding this joint project with around 5.3 million euros.

DCCTL: Compact transmission lines for high direct voltages

The German energy transition is causing energy generation and consumption to become more and more decoupled. In order to guarantee a reliable energy supply, it is thus necessary to expand the power grid. Yet it is not always possible to implement new transmission capacities in the form of overhead power lines – in some cases a solution must be implemented underground.

Gas-insulated transmission lines (GIL) for direct current voltage are one promising solution in this area. This is the focus of the **DCCTL (Direct Current Compact Transmission Line)** project, which aims to further develop compact gas-insulated transmission lines for DC voltages of 500 kilovolts. The hope is that they will form the technological basis for a highly efficient and cost-effective transmission of up to 5 gigawatts of electricity per system. Gas-insulated transmission lines require comparatively little space and can also be installed above and below ground. This type of power line has only been used for AC voltage systems up to now. The scientists participating in the project want to now also utilise GIL technology for high voltage direct current transmission (HVDC). A test plant is being planned for 2016.

DCCTL could play an important role in the design of future energy transmission systems in Germany. An advantage of this technology is that it can be comparatively low maintenance despite the high mechanical and thermal loads. This project can thus make an important contribution to the expansion of the grid. Other participants in this project – which is being coordinated by Siemens – include the Ostbayerische Technische Hochschule Regensburg, the Technische Universität Berlin and the Dresden University of Applied Sciences. The BMWi is funding this project with around 4.4 million euros.

A gas-insulated transmission line for alternating current (AC GIL) from Siemens installed in a tunnel

Optimised efficiency and grid compatibility

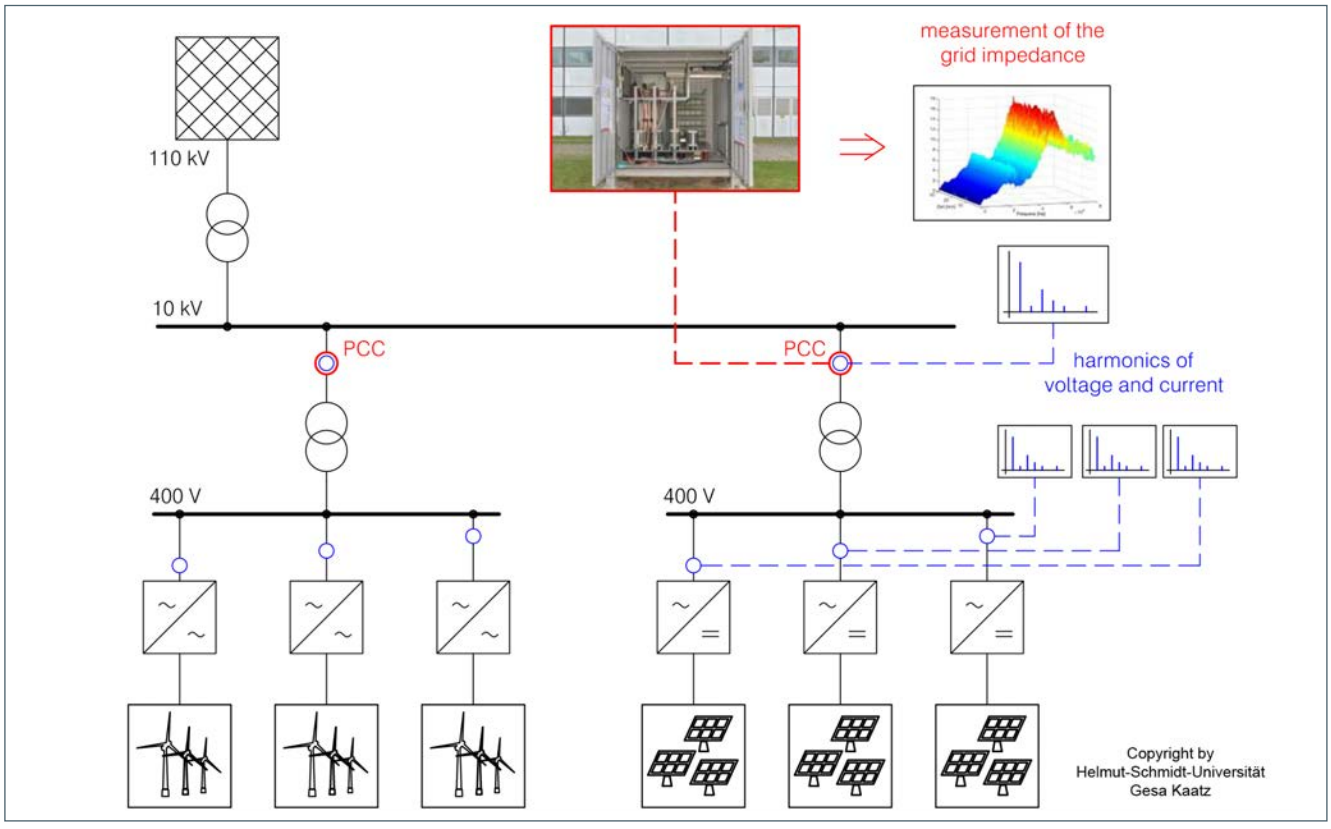
The proportion of power electronics in the grid is increasing as the German energy transition progresses. Inverters convert direct current into alternating current in PV power plants, while wind turbines use frequency converters to adjust the rotary frequency to the grid frequency. However, these converters generate harmonic currents that influence the quality of the current and voltage. The current assessment methods often do not enable the existing grid capacities to be optimally utilised.

Therefore, researchers in the **Netz-Harmonie** project want to challenge and enhance current methods to improve planning security and utilise unused grid capacities to connect up renewable energy power plants at all levels of the grid. The priority is to ensure that there will be neither any impermissible disruption to other systems and devices nor any hindrance to the cost-efficient integration of renewable energies into the power grid.

The idea is to use measurement campaigns to record the extent and superposition of harmonic currents within one voltage level and beyond the grid level. This is achieved using synchronised measurement devices at different locations in the grid to record the level of harmonics. Simultaneous measurements at precise periods in time will then make it possible to draw conclusions about the propagation mechanism of harmonics.

In addition, the frequency-dependent grid impedance (alternating current resistance) will be measured during the regular operation of the medium voltage grid. This will give a better understanding of the grid structure and the triggering of voltage distortions. It will thus be possible to determine whether renewable electricity generators and their power electronics or the grid are causing the distortions. Furthermore, it should be possible to set the converters so that the harmonic load at the grid connection point falls. The project is being coordinated by the Federation of German Windpower and other Renewable Energies (FGW) and comprises eleven other partners from the worlds of industry and research. The BMWi is funding the Netz-Harmonie project as part of the “Future-proof power grids” research initiative with around 5 million euros.

Project diagram showing how efficiency and grid compatibility can be optimised in the integration of generation plants from the perspective of harmonic currents



System integration

IN FOCUS

Weather forecasting for stable power grids

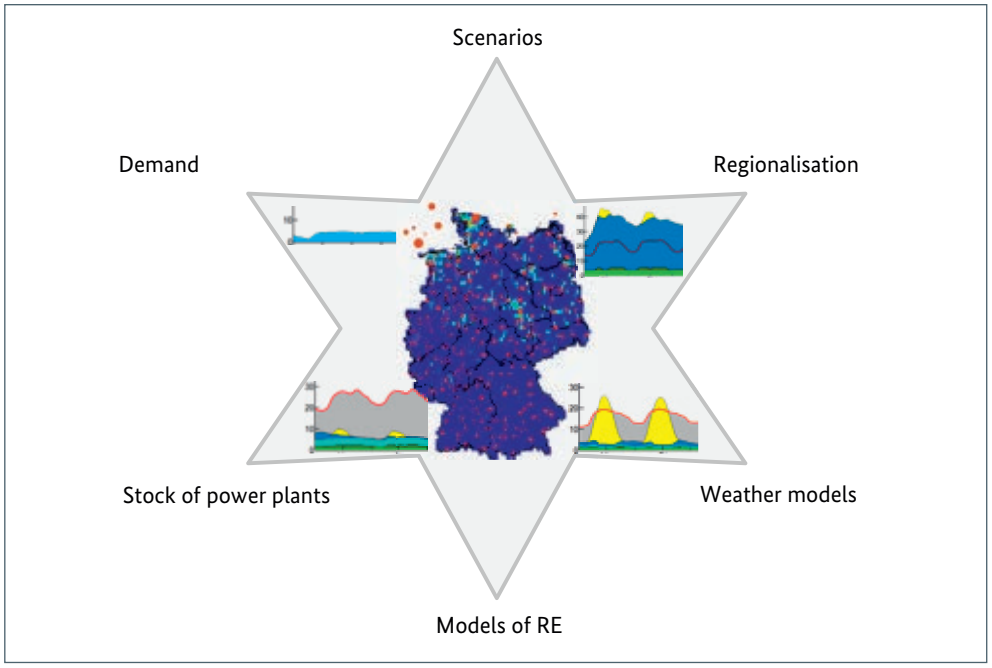
The weather has a direct influence on power grids that have a large proportion of decentralised power plants dependent on the wind and sun. In order to ensure the reliable operation and further expansion of these grids, it is thus necessary to interlink meteorology and the energy industry. This issue is being investigated by the Fraunhofer Institute for Wind Energy and Energy System Technology IWES and the German Weather Service (DWD) in the EWeLiNE project. In cooperation with the transmission grid operators Amprion, TenneT and 50Hertz Transmission, they want to develop new forecasting tools and integrate energy industry information into calculations of the weather models. The BMWi is funding this research with around 7 million euros. For this report, Dr. Kristina Lundgren, Scientific Coordinator of the EWeLiNE project at the German Weather Service (DWD) (left), Dr. Malte Siefert, Research Fellow at the Fraunhofer Institute for Wind Energy and Energy System Technology IWES, and other partners have explained their motivation and goals.

Dr. Kristina Lundgren, Scientific Coordinator of the EWeLiNE project at the German Weather Service (DWD) (left). Dr. Malte Siefert, Research Fellow at the Fraunhofer Institute for Wind Energy and Energy System Technology IWES

Why are you taking part in this joint project?
Dr. Malte Siefert (Fraunhofer IWES): Forecasting errors increase with the expansion of photovoltaic and wind energy. Even today they can already reach the level of the balancing power held for the following day. Significantly better output forecasts are urgently needed to deliver a reliable supply system. In the EWeLiNE project, we are bringing the right partners together to test targeted improvements along the process chain from the development of the weather models to their application in control rooms.
Dr. Kristina Lundgren (DWD): As improved weather forecasts are indispensable for a stable power grid, we are increasingly focussing on this subject. We are developing new products that are designed to fundamentally support grid planning.

What questions are you investigating in detail?
Lundgren: In particular, which weather events can cause problems and how our systems can better detect these events. Furthermore, we are investigating the extent to which measurements taken directly at the wind turbines or photovoltaic power plants can lead to improved weather forecasts.
Siefert: The key question here is: How can we improve the power prediction and significantly reduce extreme errors? In addition, we are evaluating the benefits of a new kind of forecasting system that can be used to assess errors in advance.
Dominique Ernst (TenneT): Our core tasks relate to the underlying data and defining use cases relevant to grid operators for the reliable management of the system and the marketing of EEG electricity. Furthermore, we transfer exceptional feed-in behaviour caused by extreme weather events and their impact into the forecasts.

What progress have you already been able to achieve?
Lundgren: The good level of cooperation has provided deep insight into the significance of meteorology for the security of the grid. An important step forward is the creation of automated products that indicate critical weather events.
Siefert: We have been able to significantly improve the forecasts using new or a combination of different methods and weather models. These are now shown live in the control rooms of the transmission grid operators and we are testing how this can support the operation of the grid.
Mathias Zirkelbach (50Hertz Transmission): The development of a demonstrator and the possibilities for its application were presented and prepared for test implementation. Special weather conditions were identified, analysed and prepared for the model. In addition, the run times for the weather models are adapted to the use cases.



The STERN project develops scenarios for the regionalised residual load time series

Selected funded projects

Precisely modelling the residual load

In order for the energy transition to be a success, it is vital that the predominantly decentralised and fluctuating energy from renewable sources is optimally integrated into the electricity grid. Detailed knowledge on the spatial and temporal behaviour of the residual load is indispensable in order to determine the required grid expansion as precisely as possible. The residual load refers to the power required minus the generation output of fluctuating energy sources at that point in time. In the **STERN** research project, the scientists at the Fraunhofer Institute for Wind Energy and Energy System Technology IWES in Kassel want to be able to reliably determine the residual load and thus make an important contribution to the needs-based expansion of the electricity grid.

The researchers are further developing existing models designed to simulate residual load time series and adapting them to the requirements of the grid expansion calculations utilised by the grid operators. The goal is to be able to model the future feed-ins from renewable energies and the resulting residual load as precisely as possible for every one of the around 360 high-voltage grid nodes in the transmission grid. In addition, the scientists want to simulate the small-scale, detailed expansion of renewable energies and their feed-ins for distribution grid studies. The researchers want to design the models in such a way that variables in the model such as different meteorological years, scenarios for expansion or arrangements of the grid can easily be taken into consideration. The BMWi is funding STERN as part of the "Future-proof power grids" research initiative with around 580,000 euros.

Renewable energies stabilise the grid

In order to operate power grids in future with a significantly higher proportion of renewable energy power plants, it is necessary for these power plants to actively contribute to ensuring transient stability. In the **Transstabil-EE** research project, the project partners – under the coordination of the Fraunhofer Institute for Wind Energy and Energy System Technology IWES – want to develop new control processes for large wind farms and solar parks that will enable the renewable energy power plants to actively contribute to the stability of the grid.

Transient stability is the ability of the grid to return to a stable state after a large disturbance – like the malfunction of an important high-voltage power line, a major electricity generator or consumer. Traditionally, these services are ensured by synchronous generators in conventional power plants. The researchers now want renewable energy power plants to participate in maintaining the frequency and voltage of the grids. Wind farms and solar parks should thus be able to create and stabilise the local grid voltage themselves for a limited period of time, especially in the event of a malfunction. The plan is to implement the required control process for stabilising the grids in many distributed units that can safeguard the global stability of the intercon-

HIGHLIGHT

More flexibility in the power grid

The more decentralised photovoltaic power plants and wind turbines feeding power into the power grid, the more flexibility options will be needed to compensate for the deviations between generation and consumption at a distribution grid level. Disparities between power generation and consumption have up to now only been balanced out within the existing energy balancing markets at a transmission grid level.

In the **Flex4Energy** research project, the project partners under the coordination of StoREgio aim to develop a trading platform offering potential for flexibility at a distribution grid level. This potential for flexibility could be provided in the form of storage systems, as well as controllable loads or consumers.

Imbalances between the supply and consumption of electricity lead to fluctuations in voltage and frequency in the grid. As the proportion of the electricity supply accounted for by renewable energies rises, the need for greater control will increase sharply. Since most of the power generated from renewable energies is fed into the system at a distribution grid level, regional balancing mechanisms can reduce the need for balancing at a transmission grid level and thus the burden placed on it. The project partners aim to develop these types of balancing mechanisms in the form of a cloud-based trading platform, to which sellers and buyers of this potential flexibility can connect via a secure communications link. The potential for flexibility is created, for example, through the installation of a storage system that is not permanently operated at full capacity for its primary function. When the storage system is idle, it can offer its capacity via the trading platform. The resulting profit margin thus improves the return on investment for the storage system.

The central instrument of the trading platform is a flexibility manager. The flexibility manager handles the supply of and demand for flexibility potential on the platform and tries to optimise the economic benefits for each partner. A new feature is that the trading strategies take the current status of the grid into consideration. This should avoid any situation where the supply of energy between two trading partners leads to bottlenecks on the grid. Another main focus of the project is security. In an energy system that includes highly networked communications, it is critically important to provide protection against unauthorised access and to stabilise the system against partial power cuts.

Alongside StoREgio, other participants in the project are the energy supply company ENTEGA, the Fraunhofer Institute for Experimental Software Engineering IESE, the Fraunhofer Institute for Solar Energy Systems ISE, the Darmstadt University of Applied Sciences and the storage system manufacturer ads-tec. The BMWi is funding Flex4Energy with around 2.8 million euros.

The scientists aim to implement and test the contribution of renewable energies to the stability of the grid at the SysTec test centre for smart grids at the Fraunhofer IWES. This will enable them to test the innovative control systems in a realistic environment. The project will thus contribute to the integration of a higher proportion of wind and solar energy into the grid and at the same time safeguard the stability of the grid. Alongside the Fraunhofer IWES, SMA Solar Technology AG, the University of Kassel and the University of Rostock are participating in the project. The BMWi is funding Transstabil-EE with around 1.9 million euros.

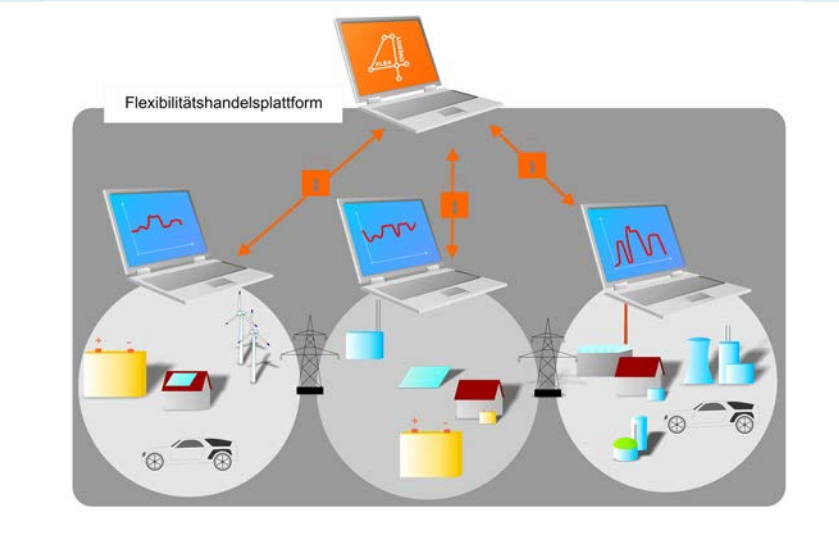
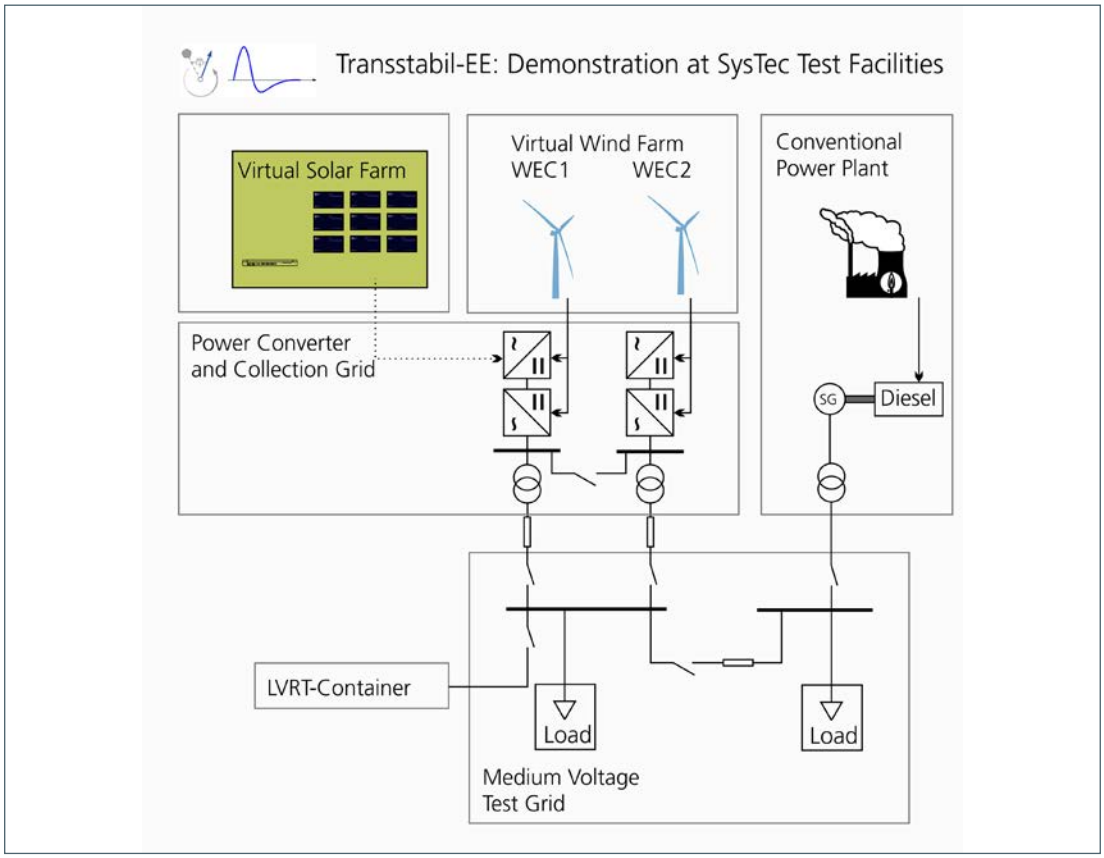


Diagram representing the flexibility trading platform of the Flex4Energy project



Transstabil-EE: Diagram of the test set-up for a wind farm connected to the medium voltage test grid

nected grid or separate subsections of the grid without communicating with each other in the event of a malfunction.

Reducing the load on the grid with solar power storage systems

In cooperation with the KfW bank (Kreditanstalt für Wiederaufbau), the German Federal Government has established a market incentive programme for battery storage systems for photovoltaic (PV) power plants connected to the grid. In the **Scientific Measurement and Evaluation Programme for Solar Power Storage** research project, the RWTH Aachen University is investigating PV storage systems in order to quantify and evaluate their impact, especially on the power grid. The researchers also want to carry out research into the economic effect of an increasing level of own consumption from solar power.

The German Federal Government hopes to reduce the burden on the grid and the electricity market with PV storage systems. These goals can be achieved if the majority of new PV plants are additionally equipped with a storage system in the future. However, the actual impact of individual measures can only be roughly estimated in advance.

Therefore, the scientists are conducting a measurement and evaluation programme within the project to enable statistical analyses of the size of the systems, the technology utilised and their storage capacities. It will thus be possible to investigate the potential and effectiveness of PV storage systems and also the difficulties faced in real operating environments. In addition, the researchers will use the resulting data to also validate, improve and optimise existing models and simulation methods for further analyses.

The knowledge gained is being made available to the public by the researchers on a web portal. They are also publishing a report annually to make this large pool of data available to industry, science and politics. The latest results from the accompanying research show that about 25,000 decentralised storage systems were already in operation in the middle of 2015. A steady fall in prices has also been noticeable, especially in the case of storage systems using lithium-ion batteries, which has brought these systems to the attention of both manufacturers and consumers since the middle of 2014. The BMWi is funding the measurement and evaluation programme with around 730,000 euros.

Energy efficient buildings and districts

Almost 40 percent of primary energy is consumed in homes, offices, swimming pools, schools, etc. Buildings and districts consume energy for heating and cooling, as well as for hot water and lighting. In view of the energy policy goals of the German Federal Government, there is great potential for savings in this area. Modern heating and cooling technologies, energy efficient building shells and renewable heating are key factors in the success of the energy transition in Germany. In future, the priority will be to further optimise innovative technologies and concepts for new and existing buildings and to intelligently network them with one another. The Energy in buildings and districts research network (Forschungsnetzwerk Energie in Gebäuden und Quartieren) initiated by the Federal Ministry for Economic Affairs and Energy (BMWi) is creating the necessary synergies in this area by bringing together stakeholders and themes. It will thus become an important interface between research, industry and politics with the aim of accelerating the transfer of research results into practical applications.

Market developments in Germany and across the world

The German Federal Government has set ambitious targets for 2050 of achieving an almost carbon neutral building stock and has presented its **Energy Efficiency Strategy for Buildings (ESG)** for this purpose. The measures formulated in this strategy aim to further reduce energy consumption in buildings in future and at the same time promote the expansion of renewable energies. How will Germany live in 2050? The vision is for buildings and districts to act as intelligently networked energy units.

The energy transition can only be achieved on the back of a successful heating transition (also see “In Focus”, page 90). In the past few years, renewable energies accounted for less than 15 percent of the entire heating supply compared to around 30 percent of the gross supply of electricity. In comparison to the electricity sector, the transition in the heating sector is significantly more difficult to implement. It is characterised by a high level of heterogeneity and complexity in terms of property owners and operators, heating technology and system sizes, building types and fields of application.

Only 13 percent of heating systems in Germany are considered to use state-of-the-art technology; more than three quarters of the around 18 million systems are more than ten years old and still use fossil fuels such as oil, gas and coal. The potential offered by the heating transition, which lies dormant in boiler rooms in German cellars and could be exploited in the form of cogeneration (CHP) technology or the integration of renewable energies, is enormous. Decentralised CHP plants that lie close to the consumer have the advantage of reducing the burden on the grid while stabilising it at the same time and already make an indispensable contribution today. However, it is the infrastructure of heat distribution systems (local and district heating) that offer the most sensible option for integrating CHP and renewable energies into heating supply systems for cities and districts.

In January 2016, the BMWi started the new **Energy Efficiency Incentive Programme (APEE)** with a package of funding measures for heating and ventilation. The goal is to start a modernisation offensive for boiler rooms in cellars – which offers great potential for the integration of solar heating. **The National Action Plan on Energy Efficiency (NAPE)** is also making an important contribution in this area. Since January 2016, one measure within the NAPE is for district chimney sweeps to attach an efficiency label to all boilers that are more than 15 years old – this will affect around 13 million old boilers in the next few years. The heating label should act as an incentive to invest in more modern and efficient systems.

Solar heating offers great potential both domestically and internationally. A study carried out by the Fraunhofer Institute for Solar Energy Systems ISE forecasts that a third of decentralised heating systems and two thirds of centralised systems in heating grids could be equipped with solar heating by 2050. The global market for solar heating continues to grow. According to an analysis by the "Solar Heating & Cooling Programme" (SHC) of the International Energy Agency (IEA), around 375 gigawatts of thermal output from solar collectors was installed globally at the end of 2013. Since 2012, the market has grown by 1.8 percent.

Many of the around 19 million residential houses and three million non-residential buildings in Germany have not been renovated or have only been partially renovated. This could potentially save up to 80 percent on energy requirements. The aim is to further exploit this potential through research and development activities. The 10-point energy agenda published by the BMWi includes a renovation roadmap for Germany as an important project for the energy transition. It is the first contribution made by the Energy Efficiency Strategy for Buildings that was presented in 2015, which focuses on the entire building stock in Germany and sets out the fundamental aspects of the future energy policy agenda.

Progress in research and development

A successful example of the contribution made by BMWi funding in the area of buildings that is particularly worthy of mention is the **Neckarpark Urban District** research project. A new city district with around 450 apartments, hotels and commercial property is being planned and constructed on the area covered by the former Bad Cannstatt railway freight depot near Stuttgart – which is being provided with heat sourced from wastewater. This project with a funding volume of around 4.3 million euros is an example of an ambitious research project with an accelerated transfer of its results into practice. The project demonstrates how a highly efficient, economically viable and safe energy supply and the optimal utilisation of existing infrastructure can be realised in our cities.

Cities and communities have been encouraged to implement the climate protection goals of the German Federal Government in their urban development processes. Universities and other campus-type properties can play a leading role and provide important impetus for the overall urban development of their respective cities through their central administration, specialist expertise and heterogeneous building stock. New research approaches supported by the BMWi in this area include, for example, the **EnEff:Campus** research initiative (see EnEff:Campus research initiative, page 100) with a funding volume of around 5.1 million euros. In 2002, the Leuphana University of Lüneburg set itself the goal of achieving a carbon-neutral campus. Since then the university campus has been redeveloped with a focus on urban planning and energy provision. The goal is to switch the energy supply to renewable energy sources and also integrate a low-energy heating system and a seasonal heat storage system.

This and many other pilot projects are delivering comprehensive scientific data through the accompanying research funded by the BMWi in the "Energy-optimised building EnOB", "Energy efficient city EnEff:Stadt" and "Energy efficient heating EnEff:Wärme" research initiatives.

IN FOCUS

The heating transition – the path to an efficient and carbon-neutral heating supply

The heating/cooling sector accounts for more than half of the energy consumption in Germany and is thus an important area requiring action for the energy transition. The German Federal Government formulated its goals and methods for exploiting the potential in this area in its "National Action Plan on Energy Efficiency" (NAPE). The target is to save 20 million tons of CO_2 by 2020, with a quarter being achieved through efficiency measures alone. In addition, the building stock should be made almost carbon-neutral by 2050 – i.e. releasing no CO_2 as far as possible – and require around 80 percent less energy than in 2008. It is thus clear: There is significant savings potential for heating and cooling purposes lying dormant within residential and commercial buildings that needs to be awoken – which is why there is also talk of a heating transition.

What makes the heating transition one of the most important components of the energy transition? Buildings account for almost 40 percent of the energy consumed in Germany. Furthermore, many of the 19 million residential house and three million non-residential buildings have not or have only been partially renovated from an energy perspective and thus fall far below their efficiency potential. What's more, the majority of the existing building stock will require maintenance work in the next few decades that will allow energy-related improvements to be completed at the same time. Whether it is a solar heating system, biomass heating system, thermal insulation measures or efficient heat pumps – every one of these technologies reduces CO_2 emissions and energy costs. Refitting heating systems and installing new heat pumps alone could save 2.5 million tons of CO_2 emissions from heating by 2020. The Federal Ministry for Economic Affairs and Energy has thus been increasingly providing funding through the KfW bank (Kreditanstalt für Wiederaufbau) to private households, companies and communities who want to cover their heating requirements through renewable energies since April 2015.

Research and development for "renewable" heating

Research and development is still required on the path towards a renewable heating supply. While renewable energies have become firmly established in the electricity sector, there is still some way to go in the heating sector.

The district heating system operated by Stadtwerke Jena

The vast majority of systems are still dependent on fossil fuels here. Therefore, the proportion of heating accounted for by renewable energies is still below 15 percent.

The BMWi is thus funding research and development into concepts and solutions for the heating transition within the 6th Energy Research Programme. In the **"EnEff:Wärme – Research for Energy Efficient Heating and Cooling Networks"** research initiative, the Ministry is supporting projects that are investigating and further developing a variety of aspects within this subject area. These aspects concentrate, on the one hand, on concrete innovations for components and systems and, on the other hand, on supply strategies based on assumptions about future demand. This will be influenced by demographic change, which will lead to a higher proportion of single-person households, and also technical factors, such as improved insulation of the heating network and buildings.

Integrated energy and heating concept for Jena 2050

In October 2015, the **EWK Jena 2050** pilot project was completed. The result was an integrated energy and heating concept for the City of Jena. The main feature is the restructuring of the heating supply system by 2050. The concept takes account of changing customer

behaviour, caused by, amongst other things, demographic change and improvements in heating technology. Stadtwerke Jena thus anticipates a fall in the heating requirements of between 16 and 34 percent by 2050. This new plan for the future incorporates this challenge as well as efficient central and/or decentralised heat generation plants and renewable energy sources for heating and electricity supply systems. This integrated approach should enable the system to adapt flexibly to demand and also make it easier to manage future investment decisions for the energy-related renovation of buildings and districts. The BMWi provided funding of around 850,000 euros for this project carried out by the Stadtwerke Energie Jena-Pößneck.

Solarisation of district heating systems

Solar power plants for district heating systems are medium to large-sized systems that have an output up into the megawatt range. The AGFW – the Energy Efficiency Association for Heating, Cooling and CHP – predicts that heating systems in Germany will require 800,000 m² of solar collectors by 2020. The design and operation of these installations are decisive factors in ensuring energy efficient yields. In the **SolStand** research project, the Department of Building Energy Systems and Heat Supply at the Technische Universität Dresden and the company Viessmann (a manufacturer of heating, industrial and cooling systems) is carrying out research into the cost saving potential of standardisation measures in the expansion of solar power for district heating systems. There are still no standards for the coupling of solar heating systems with district heating systems. These district heating systems already possess the infrastructure for distributing and in some cases storing renewable energies and stand out – as is the case with solar heating systems – due to their comparatively low operating and consumption-related costs. In order to be able to sensibly combine these previously separate areas, the project team aims to identify new technical solutions and reduce the still relatively high investment costs involved. The BMWi is funding this project with around 860,000 euros.

Systemic approach instead of individual solutions

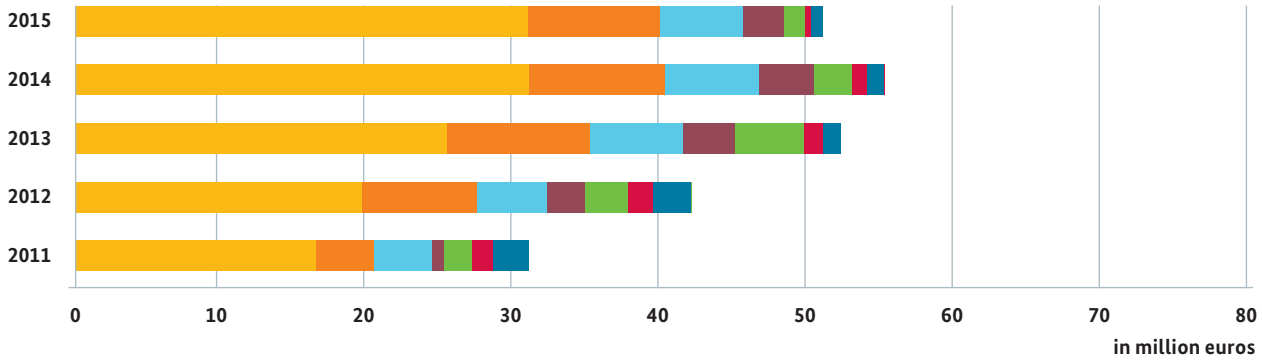
Looking at the bigger picture is an important characteristic of research and development into energy efficient buildings and districts. This starts with the fact that heating supply systems incorporate a diverse range of different technologies and a heterogeneous landscape of stakeholders. Some of these stakeholders also fulfil a number of different roles simultaneously. For example, building owners are consumers on the one hand and producers on the other hand as the operators of heating systems. The BMWi thus focuses on a systematic approach to generating synergy effects from the interaction between stakeholders, components and strategies.

Wettesingen collector field: 200-T SPL vacuum tube collectors from Viessmann

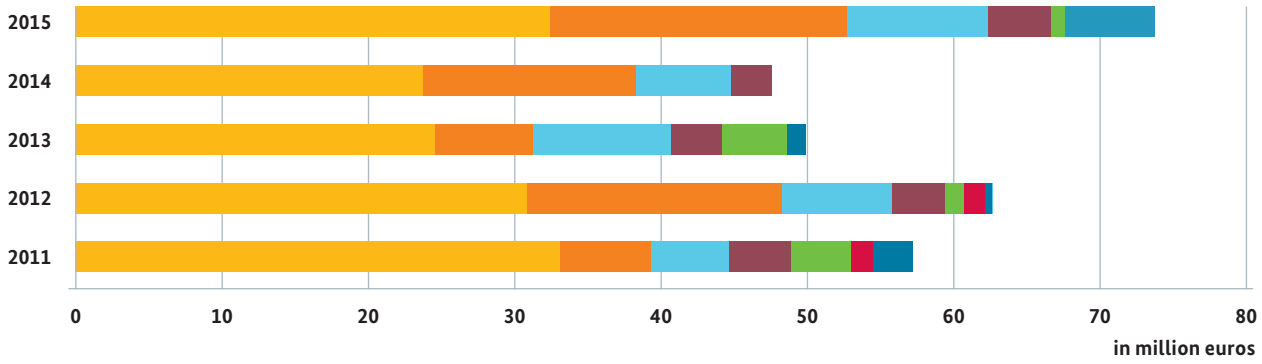
The accompanying research initiatives of EnOB, EnEff:Stadt, EnEff:Wärme and low temperature solar heating were combined into a new research project at the start of 2016. The focus is being placed on overarching and system-oriented accompanying research that will take into account all funded demonstration projects and also incorporate innovative technologies from the areas of research and development (see “In Focus”, page 94)

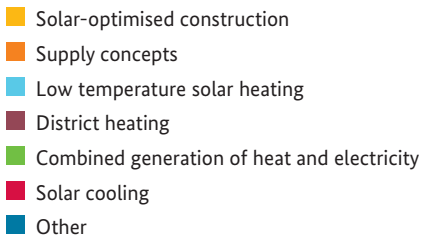
As part of the “Buildings and Districts” research area, the traditional applications for low temperature solar heating are the heating of water and contributing to heating systems in houses and apartment blocks. The technology in this area has reached a high level of technical maturity. However, heating costs still need to be reduced significantly. In the context of the heating transition, broader issues are at the forefront of research and development into solar heating: the integration of solar heating into heating systems, the solarisation of heating grids and the further development of solar active houses or zero energy houses. One of

Energy efficient buildings and districts: Distribution of funding between 2011 and 2015



Energy efficient buildings and districts: Trend in the volume of newly approved funding since 2011





the most promising concepts for achieving the almost zero energy standard called for by the European Union is being researched in the **SolarAktivHaus** in Freiberg (also see Highlight, page 96) or the **Niedrigst-Energie-Hotel** (also see "Renovation to create a low energy hotel", page 95). Solar active houses are by definition fitted with solar collection systems, with which at least 50 percent of the heating requirements are covered by solar heating. Zero energy houses cover their average external energy consumption over the year through their own energy generation, for example, using solar power plants.

Energy efficiency projects are being evaluated through trinational cooperation in Karlsruhe (Germany), Salzburg (Austria) and Winterthur (Switzerland). In this transnational cooperation, the three **D-A-CH** cities (Germany-Austria-Switzerland) with varying national policy conditions are exchanging their experiences, learning from one another and implementing innovative projects and ideas in the area of energy efficiency. This type of international research cooperation is increasingly gaining importance. In this context, the two working parties "Renewable Energies" and "Energy End Use Technologies" at the International Energy Agency (IEA) should be mentioned: Here, scientists carry out research and discuss numerous technology initiatives in the areas of, for example, energy efficient buildings, district heating systems, energy storage systems and heat pumps. The "Energy in Buildings and Communities" programme at the IEA is the largest programme with German participation.

Strategy for the research funding

Exploiting and expanding the potential to increase energy efficiency through innovative technologies and their intelligent, systematically designed application in buildings and districts is the goal of the "Energy-optimised building" (EnON), "Energy efficient city" (EnEff:Stadt) and "Energy efficient heating" (EnEff:Wärme) research initiatives funded by the BMWi, including research into thermal energy storage systems and low temperature solar heating. In the "Energy in buildings and districts" research network, all of the ongoing research activities have now come together under one roof and will be systematically combined in an overall strategy.

The research network founded by the BMWi brings together application-oriented funding measures for developing innovations in the areas of buildings and districts for the construction industry. It serves as an open opportunity for all interested specialists to contribute their knowledge and perspectives to the discussion with other participants. In addition, the network also supports the funding policy of the German Federal Government for the "Energy Transition Buildings Platform" and the "Energy Efficiency Strategy for Buildings".

In early 2015, more than 200 participants from the scientific community, the private economy and politics met for the first annual conference for the research network. The participants in the working groups of the research network presented a sophisticated compendium of proposals for the cross-departmental **"solar building/energy efficient city"** research initiative launched in early 2016. The planned funding volume is around 150 million euros. Alongside technological innovations, the focus will be placed on processes and modern planning tools for new constructions, renovations and also ongoing building operations. The open exchange of ideas and the diverse range of suggestions provided by the research network will also give impetus to the nature of future funding strategies for energy research. Due to its wide-ranging expertise, the research network has become firmly established in energy research policy. It will also continue to be an important source of inspiration for funding strategies and a platform for transferring innovation in the future. Through it the BMWi is helping to sustainably improve Germany's innovative strength in the area of energy efficient buildings and districts.

In the area of energy efficient buildings and districts, the BMWi approved new funding for a total of 159 projects with a funding volume of around 73.5 million euros in 2015 (2014: around 47.2 million euros). Around 51.2 million euros was awarded to ongoing projects in 2015 (2014: around 55.2 million euros).

IN FOCUS

Accompanying research into the field of "energy in buildings and districts"

The research into energy efficient buildings and districts is supported by accompanying scientific research. Prof. Dr.-Ing. Dirk Müller, Head of the Institute for Energy Efficient Buildings and Indoor Climate at the RWTH Aachen University, is the project manager for the accompanying research BF2016 and presents its role and goals below.

Prof. Dr.-Ing. Dirk Müller, RWTH Aachen University

Professor Müller, what are the tasks of the accompanying research?
Müller: Through a systematic analysis of research demand, a methodologically sound cross-evaluation of the ongoing and concluded projects and the provision of tools and findings for all stakeholders that takes new teaching formats into account, a substantial contribution will be made to the sustainable utilisation of the funds made available. Alongside purely technical economic questions, the accompanying research should also analyse socio-economic framework conditions. After all, the success of a project is not exclusively determined by the technology or the tools utilised. The acceptance of all participants and the impact on communities must be accommodated for during the planning process, in the structure of the project and the legal and economic framework conditions, as well as in relation to the sociological added value. Therefore, socio-economic aspects have a direct and indirect influence on the transferability of the results and their wider appeal.

What goals have you set for yourself?
Müller: The accompanying research will concentrate on four main themes or building blocks: The first building block is the clear formulation of the research topics dealing with energy technology in the building sector, which will depend to some extent on state-of-the-art technology and the goals of the German Federal Government. The second building block comprises a trend analysis using available data, which can be used as a basis to evaluate the latest technological developments and their possible potential. A systematic cross-evaluation of all ongoing projects funded by the BMWi is the third and most challenging building block due to the volume of work involved. The goal is to draw conclusions across all the projects and check them by using existing data. The fourth building block is the reworking of reporting methods to provide a greater level of transparency and better subsequent use of the research results. These building blocks and the close involvement of local authorities, associations and the users of platforms, such as the research network, should support the transformation of the energy system.

Where do you want to particularly place the focus?
Müller: A new element will be the interactive project map. The key characteristics of every project will be entered into a database. Alongside the master data, it will show important key points of the research project as well as key results with links to more detailed information. Cross-project key figures and project group-relevant key figures are being developed and integrated into the descriptions of the projects. Special filter functions will make it possible to specifically search for selected parameters and topics. The level of detail can be individually defined for different user groups. The result is an interactive tool that provides a clearly structured overview.

What are the greatest challenges from your perspective?
Müller: The largest task is the analysis of all ongoing research activities funded by the BMWi. It is necessary to find and support all projects that will provide pioneering results. We need to seek ways to successfully transfer research approaches into practice more quickly together with all participants. The energy system is at a crossroads because the switch to renewable energies has to be achieved in a relatively short period of time. Power is being generated in a more decentralised and volatile manner, consumers need to adapt flexibly to the generated output and energy storage technology is gaining an entirely new significance.

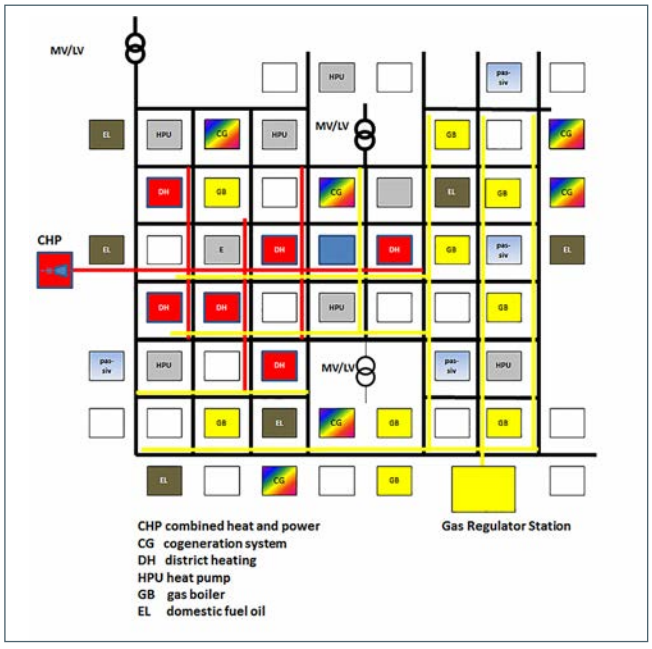
Selected funded projects

Hybrid planning process for urban distribution grids

The increasing decentralisation of electricity and heating generation as a result of the energy transition has not yet been sufficiently modelled in the planning methods used for urban energy grids. The goal of the **Hybrid planning methods for an energy efficient electricity and heating supply (HYPV)** research project is thus to develop planning and optimisation methods for the hybrid design of local authority energy generation and distribution structures. This joint project is being coordinated by the RZVN Wehr (Computer Centre for Supply Networks Wehr).

The process needs to take account of the requirements of a changed electricity market that has an increasing proportion of renewable energies and also needs to incorporate the decline in heating requirements into the planning for grids and technology funding. In addition, the methods should support the reduction in both CO_2 emissions and in the use of primary energy (fossil fuels). The researchers aim to achieve this using a multi-stage mathematical optimisation model based on a string model. Every string will represent a section of a street.

Schematic grid diagram for the hybrid design of local authority energy generation and distribution structures



The buildings located along this section of the street and their power and heating requirements will be integrated into the model with the help of current and future heating technologies. The size of the grids is thus based on the precise representation of the requirements of the buildings being supplied.

In the future, it should be possible to use this model to determine the optimal electricity and heat generation mix for a local authority. Therefore, the methods will be applied within the project to the supply structures in the cities of Constance, Sindelfingen and Düsseldorf in order to guarantee a high level of practical relevance. The Hochschule Konstanz University of Applied Sciences (HTWG) and the University of Konstanz are participating in the project. The BMWi is funding the project as part of the "Energy efficient city" (EnEff:Stadt) research initiative with around 950,000 euros.

Renovation to create a low energy hotel

The aim in the **Lowest Energy Hotel Munich** project – coordinated by the Rosenheim University of Applied Sciences – is to monitor a concept for a particularly energy efficient and sustainable hotel. The building was constructed in 1970 and was fundamentally renovated according to the passive house standard by the operator Derag Livinghotels and the industrial manufacturer COLT International. The heating, cooling and hot water are now largely provided by renewable energies and heat recovery. These measures are designed to noticeably reduce operating costs and, in particular, make the maintenance of drinking water hygiene more cost effective.

The renovation comprises a newly developed air conditioning system with fully integrated decentralised heating of hot water as a core element. The technical systems consist of a micro heat pump for every room for the purposes of heating and providing hot water. The heat source for the heat pump is a central cold water distribution circuit (approx. 14 degrees Celsius), which supplies the ceiling cooling systems at the same time. In addition, other integrated components are solar heating systems, a heat recovery system from a grey water recycling plant and a large accumulator tank that serves to store hot and cold water. The hotel is being intensively monitored for two years until the summer of 2016. The systems have been shown to operate robustly up until now.

HIGHLIGHT

SolarAktivHaus: A concept for achieving the nearly-zero energy standard

Strict energy standards will apply to buildings in the future – this is what is envisaged in the nearly-zero energy standard from the EU that will require in the near future that the energy consumed annually by newly constructed buildings is only slightly above the energy they also generate. A promising concept for achieving the nearly-zero energy standard is the SolarAktivHaus (solar active house). The focus here is on the heating requirements of a building. In the HeizSolar project, this concept is being scientifically analysed in detail for the first time under the coordination of the Fraunhofer Institute for Solar Energy Systems ISE.

A solar thermal plant lies at the heart of the solar active house. It consists of a comparatively large solar collector field that captures the sun's heat, as well as a large volume hot water storage system that can extend over a number of floors. The building envelope itself is also highly energy efficient. Passive elements, such as large window surfaces on the south side of the building, capture additional heat from the sun. It is fundamentally possible to provide 100 percent of the heating for a building just using the sun, although the heating technology is usually supplemented by additional fuel-based components.

Different designs and usages of buildings, such as houses, apartment blocks or offices, were surveyed within the **HeizSolar** research project between November 2011 and June 2015 and the way they function was analysed in detail. In the transitional periods, in particular, it was possible to supply heating for several weeks in succession purely using solar power with the help of the water storage system.

The project partners have created simulation models that have been validated using the measurement data and utilised for calculating the most cost-effective design. In the case of typical single family houses, which can cover up to 60 percent of their heating requirements through solar thermal energy, a storage system with a 3 cubic metre capacity is sufficient instead of storage systems with volumes of 6 to 10 cubic metres that were commonly used until now. It is possible to compensate for the lower solar yield, for example, by increasing the collector area from 40 to 60 square metres.

There is a need for further research in future particularly dealing with the integration of photovoltaics into the concept of the solar active house. Alongside the Fraunhofer ISE, other participants in the HeizSolar research project were Solar- und Wärmetechnik Stuttgart, Ilmenau University of Technology and the Sonnenhaus-Institut. The BMWi funded this project with around 1.5 million euros.

The Solar Office Seebronn is a solar active house

As a result of the monitoring and detailed evaluations of the system technology and the room comfort, the scientists want to test whether a purely electricity-based concept can be realised in the future. The results should enable fundamental evaluations of these types of concepts and flow into further considerations of innovative heat pump technology. The decentralised energy system at the hotel was awarded the Bavarian Energy Prize in 2014. The BMWi is funding this project with around 590,000 euros.

Field tests on absorption cooling technology for CCHP systems

The air conditioning of buildings is becoming increasingly common in Germany. Yet this does not only relate to air conditioning for comfort, as the fulfilment of workplace regulations or the cooling of technical loads (laboratories, computer centres, medical technology, etc.) also play a role and are creating new challenges for the future supply of cooling. An energy efficient option for this are absorption cooling systems based on combined heat and power plants (CHP). In the **Field test of absorption cooling technology** project, the TU Berlin is testing thermally driven absorption cooling systems for combined cooling, heat and power systems (CCHP) during operation. The scientists want to conduct research into the efficient utilisation of waste heat and demonstrate that the systems are suitable as heat pumps which will enable the extension of the running times of CHP plants as they utilise heat in summer.

The project follows on from the results of the "EnEff:Wärme – absorption cooling technology for low temperature drives" project which saw systems for district heating and the solar-based supply of heating developed to laboratory standard. The 25 plants installed in the project have a total output of around 2.3 megawatts and are distributed through Germany in 16 locations. The researchers anticipate the plants will have a 30 percent higher power density than those systems currently available on the market. In addition, the aim is to reduce investment costs by 50 percent, double the electrical efficiency and at the same time lower operating costs. The overall primary energy efficiency of the CCHP chain will be increased through the use of highly efficient absorption technology combined with district heating. Alongside the TU Berlin, other participants in the project are the Technische Universität Dresden, the Bundesindustrieverband Technische Gebäudeausrüstung and the AGFW-Projektgesellschaft für Rationalisierung, Information und Standardisierung. The BMWi is funding this project within the EnEff:Wärme research initiative with around 4.4 million euros.

Absorption cooling systems from the FAKS project

EnTool: Planning software for energy efficient buildings

The comprehensive use of modern simulation-based planning tools is constantly gaining in importance. This should make it possible to optimise energy use in buildings, districts and cities and their supply structures in the planning process and in practical application. The BMWi supports research and development into planning tools with the EnTool research initiative in the research area "Energy-optimised building EnOB".

In the **EnTool/EnEff-BIM** project, scientists at the RWTH Aachen University are carrying out research into planning, designing and optimising the operation of energy efficient new and existing buildings using modelling and simulations based on building information models (BIM). This joint project also includes the consultancy company AEC3 Deutschland, the Berlin University of the Arts, the Karlsruhe Institute of Technology (KIT) and the Fraunhofer Institute for Experimental Software Engineering IESE. The aim is to further develop dynamic building models for simulating buildings and systems. The researchers are investigating various levels of detail for the models and a variety of techniques for coupling the models with data during the simulations. The project has a high level of international visibility as it is also involved in the complementary cooperation in the IEA EBC Annex 60 project. The BMWi is funding this project with around 2 million euros.

In contrast, the **EnTool:CoSim** project is working on FMI coupling technology for different simulation tools, which can be utilised to evaluate energy technology in buildings and to design complex technical energy supply systems in buildings. The project aims to combine what was previously largely isolated expertise to create a uniform, standardised framework for the design and planning process. Other participants in this joint project that is being coordinated by the Technische Universität Dresden are the ITI Gesellschaft für ingenieurtechnische Informationsverarbeitung, the energy services company EA Systems Dresden and the Fraunhofer Institute for Integrated Circuits IIS. The BMWi is supporting this project with around 1.6 million euros of funding.

The EnEff-BIM project aims to optimise energy use in buildings, districts and cities with a new planning tool

HIGHLIGHT

LowEx: Grid-reactive buildings reduce the burden on electricity grids

As a result of the increasing proportion of fluctuating renewable energies in the energy system, the focus is being placed to an increasing extent on the demand-side management of electrical consumers. This approach involves temporarily increasing or reducing electricity consumption depending on whether there is a particularly high or low demand for electricity in the energy system at that particular point in time. Technical systems in buildings such as heat pumps, cooling machines and combined heat and power plants (CHP) in combination with thermal storage systems can also be utilised for demand-side management by incorporating the time at which power is consumed for providing heating and cooling in the energy-related evaluations of buildings and the development of innovative control strategies.

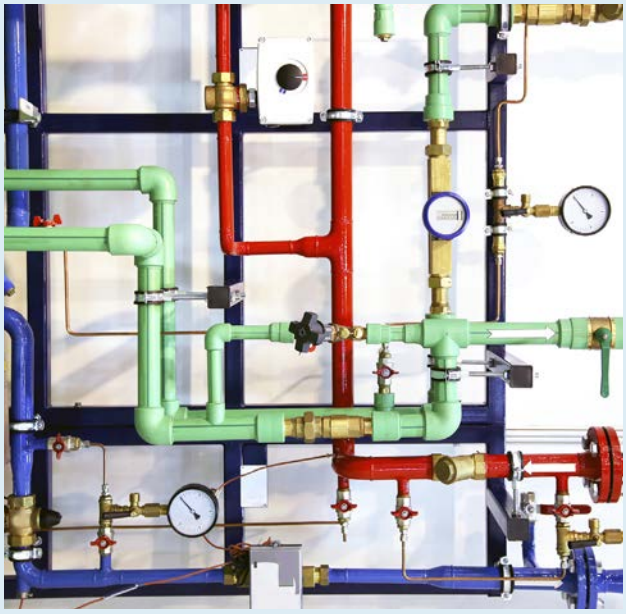
In the **Grid-reactive buildings** joint project, scientists are conducting a comprehensive investigation of buildings as part of the energy system in order to develop a consistent evaluation methodology. This is intended to allow planners and decision-makers to evaluate individual buildings and large building groups in energy, exergy and energy industry terms.

In addition, the researchers are developing proposals for how the results can be integrated into the existing standards and regulations. An important research question for the project is how buildings and building groups will behave in an intelligent electricity grid in the future and how this could positively influence the stability of the grid.

The scientists have initially completed a holistic evaluation of the building physics and energy systems in buildings. The project team has analysed and compared four electricity grid variables: the EEX day-ahead price, the residual load, the cumulative energy consumption (non-renewable share) and the proportion of wind and photovoltaic power in the electricity mix in relation to the time of day and year. On this basis, the researchers have developed two uniform and dimensionless coefficients: the "grid support coefficients" GSCabs und GSCrel. These will be used to evaluate the ability of electrical consumers and generators to support the grid in relation to the superordinate energy system. This will enable the level and times of electricity consumption for the provision of heating and cooling to be incorporated into the energy-related evaluation of buildings and the development of innovative control strategies. Furthermore, evaluation strategies are being developed for the efficiency of storage systems in buildings for excess wind and solar power as well as for the load experienced by the low voltage grid.

The project is being coordinated by the Fraunhofer Institute for Solar Energy Systems ISE. Other participants in the joint project are the E.ON Energy Research Center (Department for Buildings and Indoor Climate) at the RWTH Aachen University and the Fraunhofer Institute of Construction Physics IBP. The BMWi is funding this project with around 2.8 million euros.

Technical systems in buildings can also be utilised for demandside management in buildings



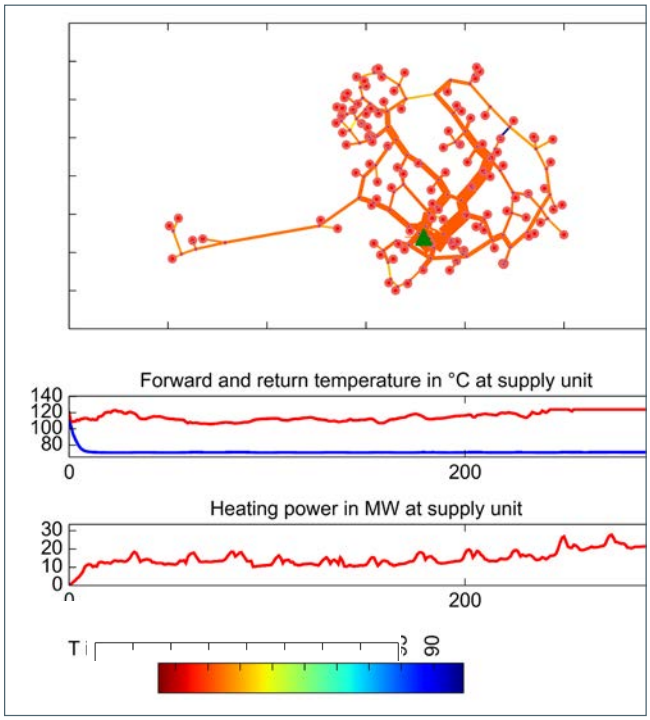
EnEff:Campus in Potsdam-Telegrafenberg: The aim is to reduce energy consumption here by half

EnEff:Campus research initiative

Universities and research institutions are drivers of innovation. Thanks to their central administration and heterogeneous building structures, they can also play a role as pioneers for energy efficiency within the energy transition in buildings and districts. In the EnEff:Campus research initiative, the BMWi thus supports a number of projects focussing on this subject.

One of the projects is **EnEff:Campus blueMAP**. An integrated energy master plan has been created at the Technische Universität Braunschweig that will act as a pilot project for planning and optimisation methods for energy-related renovation of inner city districts. An interdisciplinary team has developed measures for a sustainable supply of energy to the campus with its heterogeneous building stock by 2020 and thus to make savings on the use of primary energy of 40 percent. The BMWi has funded this project with around 1.2 million euros.

In the **EnEff:Campus Potsdam-Telegrafenberg** project, the Potsdam Institute for Climate Impact Research (PIK) has developed a concept for the energy-related optimisation of a campus comprising 56 new and existing buildings. The goal was to achieve energy savings of around 50 percent. This involved the planning and development of innovative



Graphic from the EnEff:Campus project at the RWTH Aachen University and Forschungszentrum Jülich

building and system solutions. Another participant in this project that received funding of around 1.9 million euros from the BMWi was the Technische Universität Dresden.

In the **EnEff:Campus – RWTH/FZJ** project, the RWTH Aachen University and Forschungszentrum Jülich developed a simulation tool based on real buildings. This planning tool is designed for the integrated and dynamic optimisation of the entire energy supply system including generation plants, buildings and cooling and heating grids. The development of holistic concepts for planning energy savings as efficiently as possible will be created with the help of models. The BMWi has funded this project with around 1.1 million euros.

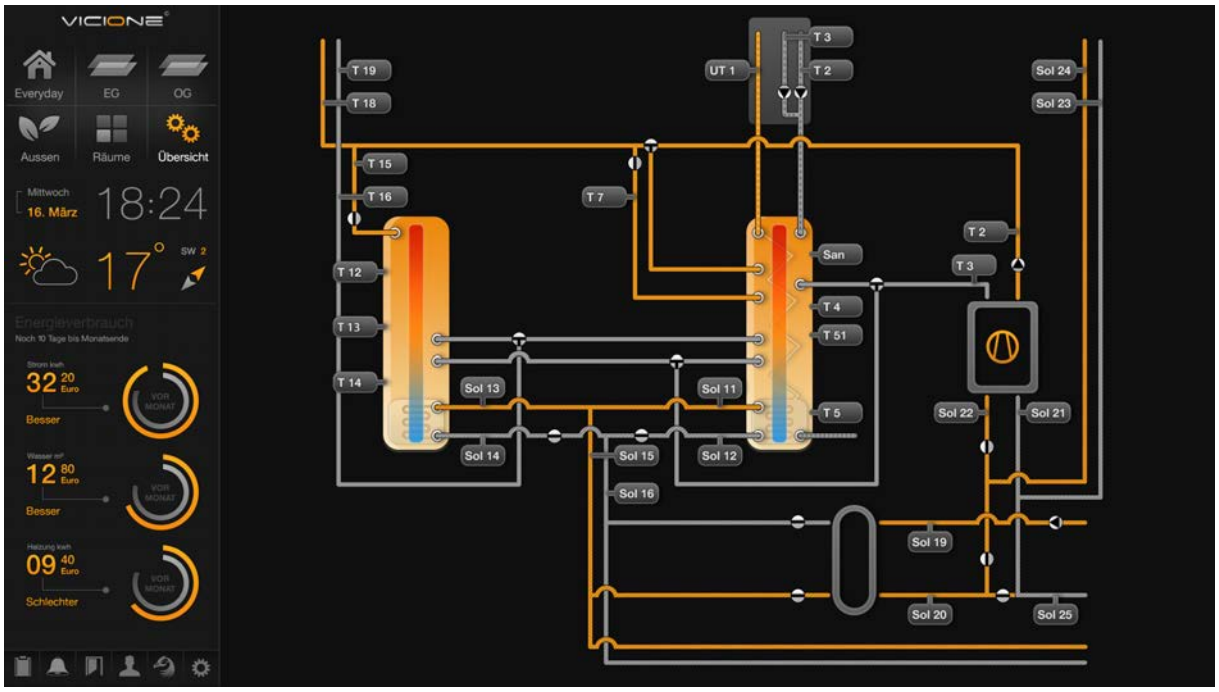
Intelligent control systems: Holistic energy management systems for buildings

Global building management systems are used to control technical building equipment and manage the optimal operation of buildings, such as with a view to controlling energy consumption. Intelligent control systems of this type make it possible to reduce the energy consumption of buildings. In order to achieve this, the **enerMAT** research project aims to further develop and disseminate energy saving and environmentally friendly building management technologies. The energy consumption of commercial and residential buildings can be significantly reduced using the approach developed in the project. The five partners in this joint project have developed a model-based design for holistic energy management systems for buildings (Building Energy Management Systems, BEMS). The scientists have created concepts and processes that enable energy savings to be made in the operation of buildings through the holistic planning and realisation of energy efficient building control and automation.

The software solution is utilising these types of energy management systems in the project development phase. This should enable users to make well-informed decisions about investments and operating costs, as well as energy savings and comfort, at an early stage.

The project is part of the research field EnBop – Energy-oriented operation optimisation in the research area "EnOB – Research for energy-optimised building". The project is being coordinated by NSC as automation specialists. Scientists at the Fraunhofer Institute for Integrated Circuits IIS, the ITI Gesellschaft für ingenieurtechnische Informationsverarbeitung, Provedo Software and the construction company FASA have also participated in the project. The BMWi has funded enerMAT with around 4.4 million euros.

enerMAT: Energy management systems for buildings



Energy efficiency in the industry, commerce, trade and services sector

Industry, commerce, trade and services (ICTS) are one of the largest energy consumers in Germany. They thus play a central role in the success of the energy transition. The potential for making savings in these sectors is especially high: The Federal Ministry for Economic Affairs and Energy (BMWi) thus provides funding for research into energy efficient and resource conserving technologies in this area. As a result of the expertise gained in research and development, the position of German industry in international competition can be strengthened further.

Market developments in Germany and across the world

Growth, employment and competitiveness in the industrial sector is increasingly linked to energy efficiency and the conservation of resources in the individual companies: Those companies that do not save energy or offer energy saving products and processes will become uncompetitive in the long run and also be unable to survive on the market in the future. Therefore, intensive research into new technologies and the further development of technologies that are not yet established on the market in the area of energy efficiency are indispensable and increasingly important for industrial production. The greatest potential for making savings in this area is the use of energy efficient drives, pumps, furnaces, efficient lighting and ventilation and compressed air systems.

Industry, commerce, trade and services (ICTS) are some of the largest energy consumers in Germany, although their share of the overall consumption has improved in the last few years: The proportion of energy consumed by this sector has fallen from 50 percent (1990) to 44 percent (2013) in around two decades. At the beginning, this was due to the reunification of Germany and the associated structural change in the new federal states. In the meantime, these effects have been sustainably displaced by the implementation of new and improved efficiency technologies along the entire value added chain for industrial production.

Energy-intensive industries play a central role in the implementation of the energy transition. They continue to deliver indispensable basic and raw materials for important future-oriented sectors in Germany. The German Federal Government‘s 6th Energy Research Programme places a key focus

on funding to increase energy efficiency in industry, commerce, trade and the services sector. Guaranteeing the application of the research results across the broad spectrum of the industrial sector is of special interest to the BMWi.

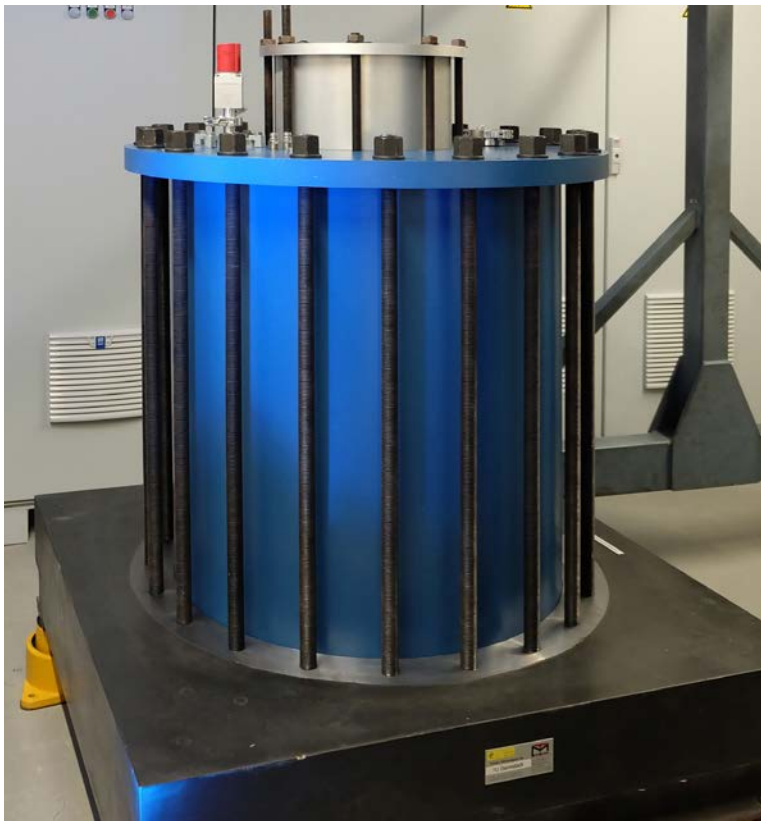
Progress in research and development

In many industrial processes, a high proportion of the primary energy used was previously lost in the form of waste heat. If this heat is utilised, it increases energy efficiency and at the same time reduces CO_2 emissions.

In the research field of waste heat utilisation, the BMWi funds the development of so-called thermoelectric modules, which generate electrical energy from waste industrial heat, in projects such as **ThermoHEUSLER** and **HighTEG**. However, the manufacturing of the required materials and systems is still expensive and laborious. The researchers have managed to produce metal alloys that were previously only available on a gramme scale on the kilogramme scale while maintaining the performance parameters – a major step towards industrial maturity. The energy saving potential offered by the utilisation of waste industrial heat across all sectors is estimated to be around 130 terawatt hours per year. The task is now to use research and development to transfer the levels of efficiency achieved in the laboratory into technical application.

In particular, cross-cutting technologies are a promising starting point for the industrial and rational use of energy. Alongside utilising waste heat from thermal processes, the use of solar process heat and innovative measurement, management and control technology, this also includes speeding up processes in the chemicals industry.

The goal in the research field of chemical process technology is to transfer energy and resource efficient processes from the laboratory to production at a faster rate. For this purpose, funding of around 7 million euros has been awarded to four joint research projects and an individual project within the **ENPRO initiative** (also see “In Focus”, page 106). Industrial players – such as Bayer, BASF and EVONIK – are working together and intensively exchanging results via the ENPRO-Connect platform. The first interim results, which were achieved in 2015, have laid important foundations for energy efficiency and will be further disseminated through the process and system technology and control systems industry.

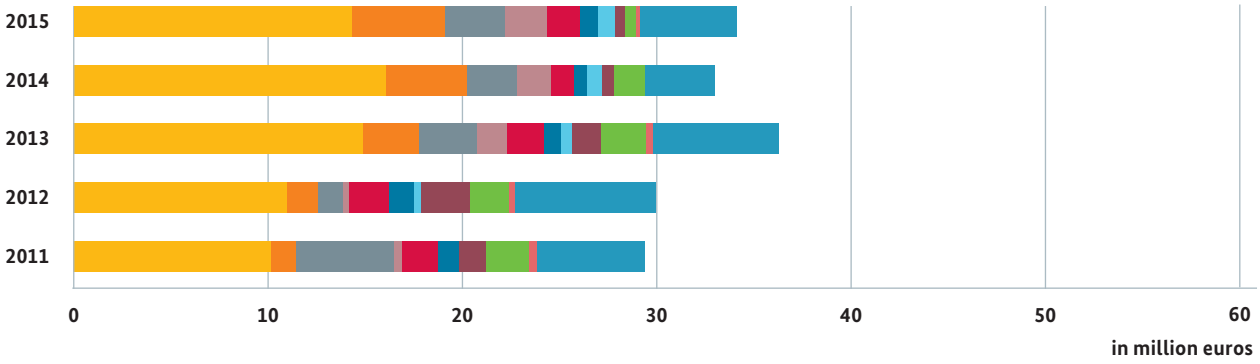


Flywheel energy storage system at the ETA-Factory in Darmstadt

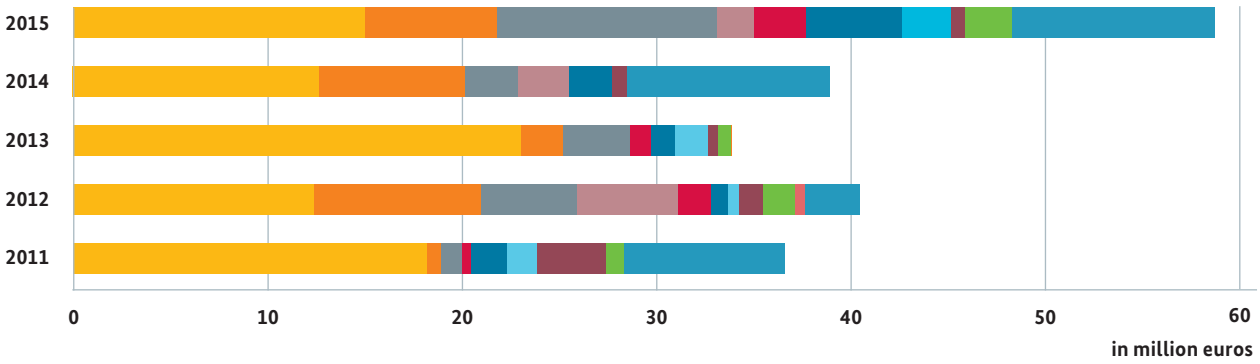
In the research field of production technology, decision-makers are placing their focus on energy-related interactions in the process chain in order to still enable the discovery of further useful effects when the options for optimising individual projects have been exhausted. The BMWi is supporting scientists in the construction of the demonstration plant **ETA-Factory** on the campus of the Technische Universität Darmstadt, which was opened in March 2016 (see image on page 102). The researchers are using the example of metal processing to observe the energy-related interactions between the aggregates across the entire factory, whereby even the building envelope and equipment are taken into account. It is anticipated that an overall energy saving of 40 percent can be achieved.

Mechanical friction between moving parts is omnipresent and the cause of significant energy losses. The area of efficiency optimised layer lubrication systems for construction and harvesting equipment has been intensively investigated by scientists in the joint **CHEOPS³** project (also see Highlight, page 109) since October 2015. The researchers are

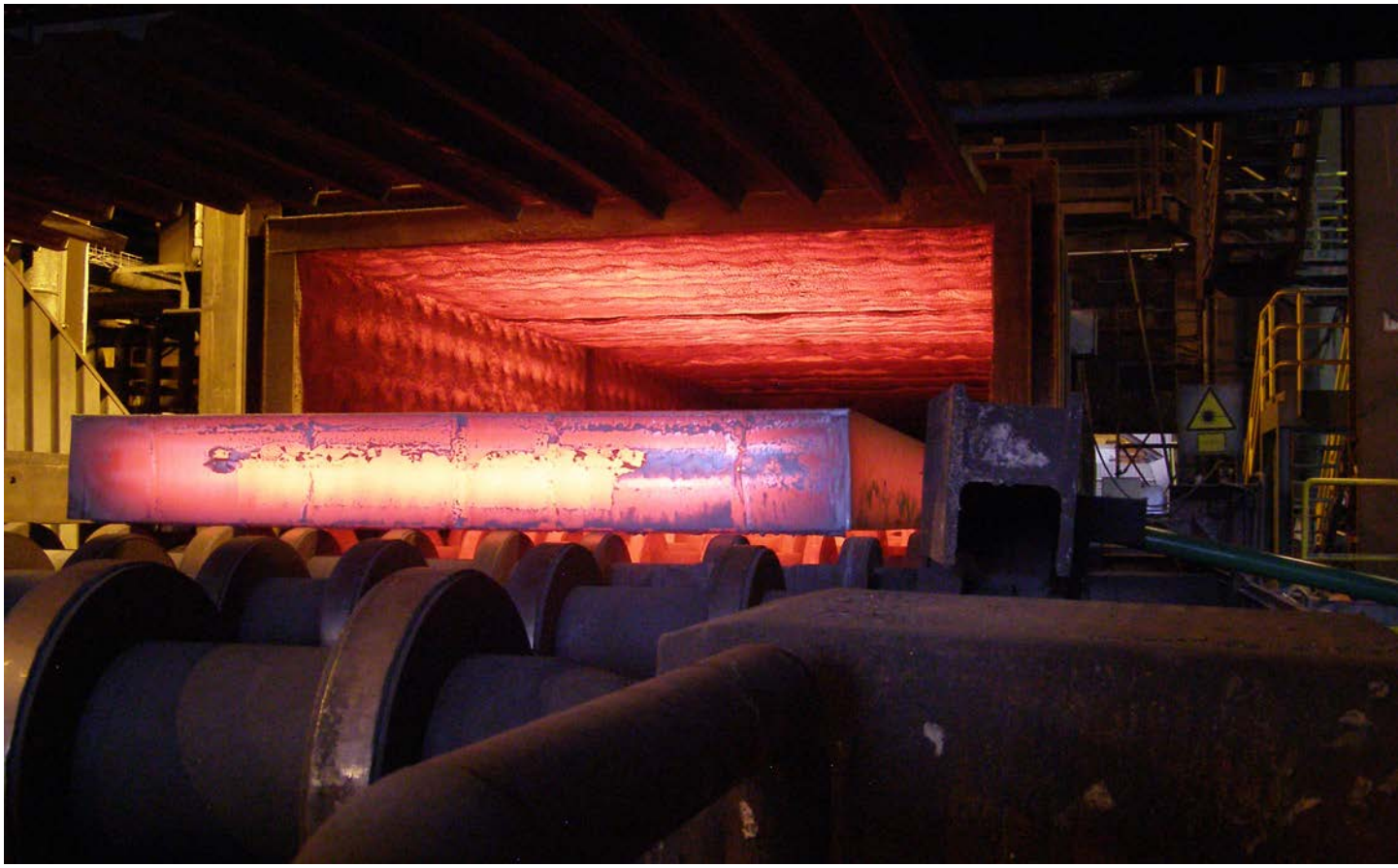
Energy efficiency in industry: Distribution of funding between 2011 and 2015



Energy efficiency in industry: Trend in the volume of newly approved funding since 2011



- Mechanical engineering, vehicle construction, electrical engineering, precision engineering, optics, EBM goods
- Chemical industry, production of plastics and rubber goods
- Heat pumps, coolants
- Mechanical and thermal separation processes
- Extraction and processing of rocks and earth, fineware, glass industry
- Heat exchangers
- Non-ferrous metals industry
- Iron and steel industry
- Industrial furnaces
- Solar process heat
- Other



The INTEGA joint project is dedicated to the industrial testing of thermoelectric generators for producing electricity from waste heat for use in the steel industry

drawing on the experience gained in the associated research projects **PEGASUS I** and **II** and are thus continuing the activities funded by the BMWi in the research field of tribology. The research projects named above are good examples of the wide variety of innovations being developed to reduce friction losses so that primary energy can be used more efficiently in the future.

Strategy for the research funding

Energy efficiency in the industry, commerce, trade and services sector (ICTS) will be an important factor in future for the international competitiveness of industry and its innovative capabilities. Therefore, increasing energy efficiency is a key issue for economic and energy policy. Around 44 billion kilowatt hours of electrical power could be saved in the ICTS sector alone by 2020.

This funding area is characterised by a broad spectrum of themes and technologies. The research topics on key strategic themes are bundled in research fields that are planned over the long term. This guarantees a flexible and targeted funding approach through interaction between the stakeholders above and beyond the boundaries of the research projects. Alongside the funding of the research fields, support is also provided to innovative individual projects to respond to research needs more flexibly and bring them to fruition.

The project funding from the BMWi into energy efficiency in industry, commerce, trade and the services sector stood at around 34.1 million euros in 2015 (2014: around 32.9 million euros) for a total of 339 ongoing projects. At the same time, there were 115 newly approved projects with total funding of around 58.5 million euros (2014: around 38.6 million euros).

IN FOCUS

Increasing efficiency through miniaturisation in the chemical industry

In chemical process technology, the measures suitable for increasing energy efficiency differ depending on the scale of production. In large plants, the measures focus primarily on the apparatus and system technology, while modularisation can generate savings in medium-sized plants. In contrast, the greatest potential in small production plants is switching from batch production to continuous production. These questions are investigated in the research field of chemical process technology.

By miniaturising known basic operations within chemical processes, reactions can be carried out continuously which means they are faster and easier to control than on a larger scale. This contributes to a more energy efficient production. There is also less of a chance of an accident with particularly reactive components. Due to lower operating costs, microreactor technology has great market potential and also enables resource conserving management during manufacturing.

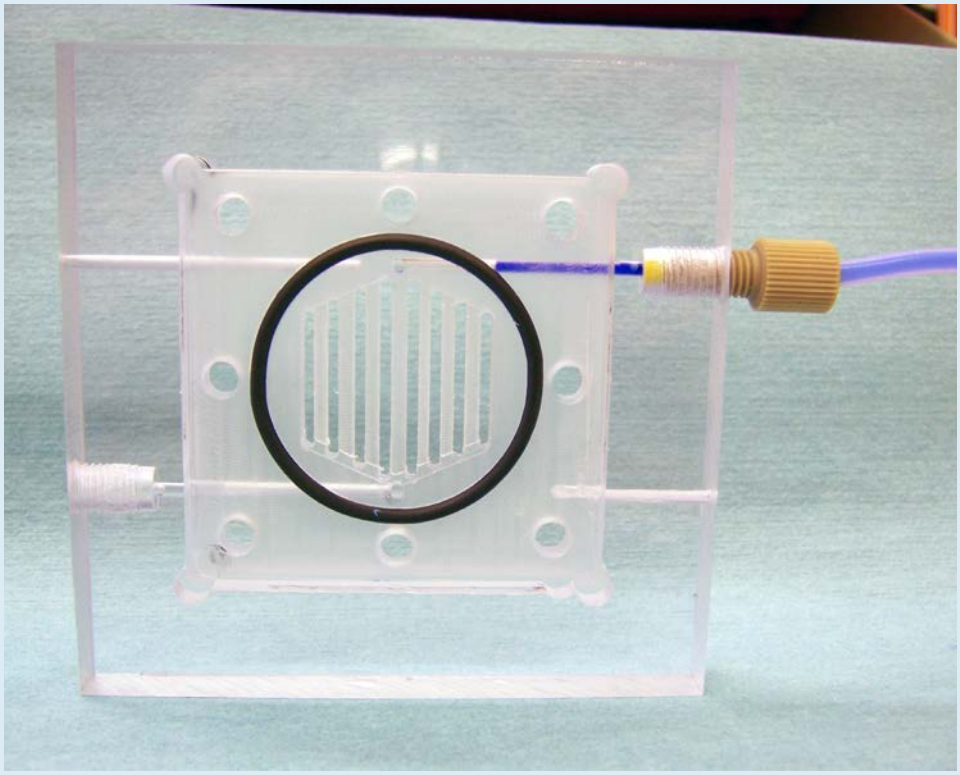
Specific fields of application will initially include the production of special chemicals or pharmaceuticals in small companies. A consortium within the **ENPRO initiative** (see the "Innovation Through Research" report for 2014, page 111) is currently investigating whether micro-processes can also be utilised in the large-scale production of chemicals, especially in relation to safety issues and the quality of the results. Some companies are already utilising this technology on a small scale at the experimental stage and have already achieved increased yields.

An important prerequisite for the practical application of micro-process technologies in large-scale industrial production is miniaturisation along the entire process chain. In general, micro-processes usually only prove advantageous when all steps and not just individual elements can be miniaturised. Therefore, the BMWi is targeting its funding on three pre-competitive joint research projects that are focussing on the further development of miniaturisation in the areas of electrochemistry, chromatography and separating technology – and thus on markets decoupled from one another. The focus of the BMWi project funding is placed on specialised companies who are facing the question of whether their individual production processes can in principle be miniaturised. All of the joint projects named above have verified that this is the case. In subsequent projects, the scientists now want to focus, amongst other things, on incorporating these process steps into a routine.

The ENPRO initiative is now using these results to investigate which large-scale processes could be miniaturised this way. Irrespective of this work, the results of all three projects are also individually exploitable. However, the combined findings from the projects can deliver a valuable overall result for the chemicals industry and thus strengthen the international competitiveness of Germany.

The joint research project **EProMiT** is dedicated to improving the recycling and thus the energy efficiency of chemical processes by designing basic operations for liquid-liquid extraction, chromatography, distillation and crystallisation more efficiently using microstructured separation technology. For this purpose, the scientists have developed microfluidic separating modules and processes and tested them on a laboratory scale. These developments should enable the continuous separation of mixtures from biotechnical and chemical processes. The modules and processes could now be flexibly integrated into existing production process in the foodstuffs and pharmaceutical industries. The BMWi funded this research with around 1.7 million euros. The project was coordinated by the Clausthal University of Technology.

Scientists in the joint project **µKontE** are conducting research into the transformation of production processes with the goal of switching from the production of chemical products in batches to a continuous process using components based on mini and micro-process technology. On the basis of example processes, the project part-



EnEl-Mi: intermediate layer during a leakage test

ners were able to demonstrate that switching to continuous production can save energy and thus reduce costs and strengthen competitiveness. The BMWi supported the project, which was coordinated by the Technische Universität Braunschweig, with around 1.8 million euros of funding.

In the **EnEl-Mi** research project, which was coordinated by Invenios Europe, a consortium conducted research into energy efficient electrochemical processes for CO_2 conversion using microreactors. The scientists have developed reactors and separation concepts based on micro-process technologies for the electrochemical reduction of CO_2 in flue gasses from production processes. Thanks to microscopic effects in the mini reactors, it should be possible to use harmful CO_2 as a raw material and so reduce the use of carbon from fossil fuels in chemical production. This process technology is not yet available for electrochemical processes and the conversion of large volumes of substances. A technical concept for the construction of small pilot plants was developed in the project that will make it possible to test their suitability in bypass operation. A subsequent project based on these results, which has been awarded funding of around 900,000 euros by the BMWi, started in February 2016.

The project is being coordinated by the DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e. V. An exchange platform will also be developed to guarantee the compatibility of the results across applications and ensure the transfer of knowledge and results between the participants in the ENPRO initiative.

Selected funded projects

Energy efficient waste gas treatment

Waste gas is generated through the handling of residual waste in mechanical-biological waste treatment (MBWT) plants. According to the 30th Federal Ambient Pollution Control Act (BImSchV), these gases must be collected and fed into a waste gas treatment system. In order to comply with the emission limits (dust, carbon and nitrous oxide, etc.), energy-intensive purification systems are currently used. These can account for around 70 percent of the total specific energy consumption of a MBWT plant.

This topic is the focus of the **EnAB-Energy efficient exhaust treatment** project that aims to increase the energy efficiency and effectiveness of the processes in MBWT plants. In cooperation with a plant operator and an industrial partner, the scientists have attempted to significantly reduce the specific energy consumption in a MBWT plant in Aurich by carrying out a series of technical tests on-site on a large scale. In addition, a pilot plant-scale modified waste gas management system with alternative purification technologies was employed.

With partial modifications to the MBWT plant, it has already been possible to reduce the specific primary energy consumption during the processes and in waste gas treatment from 99 to 89 kilowatt hours per ton of treated waste and thus save 600,000 kilowatt hours per year. If transferred to the entire plant, initial assessments estimate that the primary energy consumption of 6 million kilowatt hours per year could be reduced by more than 30 percent. In the long term, the researchers also want to further develop a process and waste gas treatment technology adapted for MBWT plants.

The project was coordinated by the Department of Processing and Recycling at the RWTH Aachen University. In addition, the University of Stuttgart, PlasmaAir and MKW – Materialkreislauf und Kompostwirtschaft GmbH as the plant operator participated in the project. The BMWi has funded the joint project with around 1.5 million euros. The research will be continued in a subsequent project called “EnAB – Energy efficient exhaust treatment 2”.

The Großefehn MBWT plant was used by scientists to conduct a series of tests on waste gas treatment

HIGHLIGHT

Dry and minimal quantity lubrication for tribological systems

Due to the typically low speeds of construction and harvesting equipment, the bearings do not operate in the hydrodynamic range (full lubrication) but are rather operated using a dry or mixed lubrication regime. This leads to a high level of friction that causes increased wear and energy losses.

Scientists in the joint project **CHEOPS³ (Characterisation of efficiency optimised layer lubrication systems)** are carrying out research in this area, under the coordination of the company iwis Motorsysteme. The focus is being placed on optimising tribological systems in drives, bearings and chains. Tribological systems in terms of mechanical engineering comprise machine surfaces that interact with one another and whose movement is relative to one another. Energy is lost through static, sliding and rolling friction. In order to reduce this friction, lubricants are used that are difficult to apply in slow moving systems.

The goal of the research work is to enable these kinds of tribological systems to no longer require any lubrication or only minimal or even only a single initial lubrication with oil or grease. For this purpose, the project team aims to develop suitable layer systems (such as DLC (diamond-like carbon), gradient, doped, metal-based and hybrid layers and bonded coatings), apply them to materials and test their tribological behaviour.

Components that are later treated with these layers should thus require almost no maintenance. The partners expect an improvement in energy and resource efficiency due to the consistent reduction in friction, the partial elimination of lubricants, the simplification of component geometries and the fact that it will no longer be necessary to use seals.

In the project, the Fraunhofer Institute for Material and Beam Technology IWS is carrying out some of the work on the development of the coating technology. In this area, the researchers are utilising the experience gained in the funded projects **PEGASUS I** and **II** (see the "Innovation Through Research" report for 2014, page 111). These projects dealt with the superlubricity of machine components using diamond-like carbon coatings (DLC) and special lubricant components in the automobile sector. As an alternative to the DLC coatings, the Surface Engineering Institute (IOT) at the RWTH Aachen University has developed a nitride hard coating and optimised it for the use in minimal quantity lubrication or dry running tribological systems used by the industrial project partners.

When the results are applied in the area of mechanical engineering, the scientists expect that dry or minimal lubrication will lead to the machines being easier to service and also expect a reduction in energy losses of up to 50 percent. In addition, the partners anticipate longer service lives for the components which thus further increases in energy efficiency due to the reduction in wear. 12 partners are participating in the project, including research centres and universities, automobile and supply companies. The BMWi is funding this joint project with around 7 million euros.

Form honing tool from the Hybrid Honing research project

Hybrid honing process for the energy efficient production of low-friction crankshaft drives

As a precision finishing process for internal cylinder contours, honing is an important process step in the production of piston stroke machines (engines or compressors). This type of machining as a production process was previously carried out using conventional honing processes and tools with the goal of producing cylindrical forms. A honing tool, the so-called honing template, is used to guarantee the dimensional accuracy of the drilling contours even when the cylinder head is mounted. This leads to excessive use of materials and high processing costs and thus to high energy consumption in the production process.

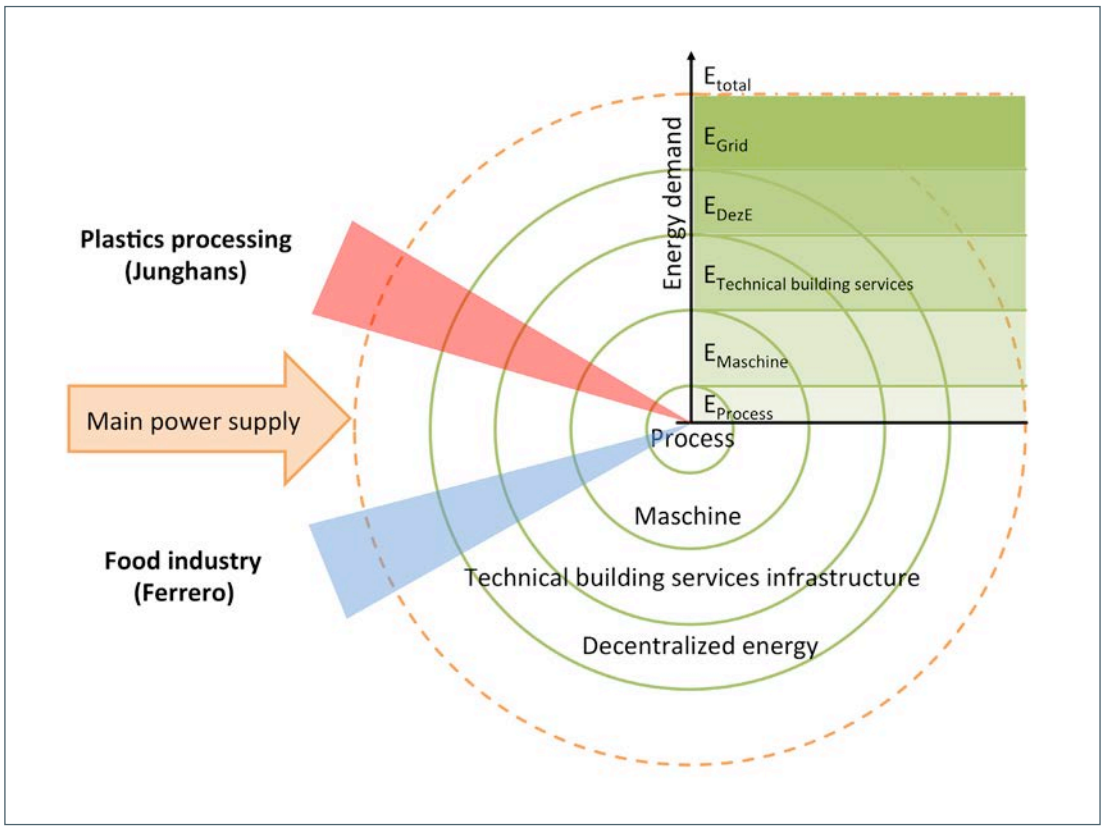
In the **Hybrid Honing** project, the partners thus aim to develop a new tool with highly dynamic piezo-controlled cutting as well as the corresponding production process. After determining the contours and generating the process-based data, the aim is to enable the machining of 3D honing contours that meets specific requirements. In doing so, the scientists and engineers are taking the entire concept of the machine, the tool, the processes and the measurement technology into account.

The result should be a new tool design and honing process that overcomes the disadvantages of the previously used conventional process. In the future, piston stroke engines should become more energy efficient as more precise machining methods will lead to less friction and oil loss. Overall, it would thus not only be possible to save energy within the industrial production process but also in the later operation of the resulting piston stroke engine. This joint project comprising six partners is being coordinated by Nagel Maschinen- und Werkzeugfabrik GmbH. The BMWi is funding this work with around 1.8 million euros.

Energy efficiency in the food and plastics industries through the superordinate control of energy flows

Intelligent energy management has the potential to make significant savings on operating costs for industrial companies and at the same time have positive effects on the environment. Through the use of superordinate management and control of energy flows, the partners in the **Smart Consumer** research project aim to significantly reduce energy demand in production – using the two examples of the plastic processing and the food industry. The project is being coordinated by the University of Kassel. The scientists are developing an approach to improve energy efficiency in existing machines through the systematic coupling of energy flows in the production process, technically refitting buildings and supplying energy with the help of intelligent measurement, management and control technology. In combination with a simulation-based, superordinate control system, which will be developed in this project, it will create the foundations for a so-called Smart (Industrial) Consumer.

In the Smart CHP subproject, the focus is being placed on improving the supply of energy from plastic processing plants. The second subproject Smart Klima is dedicated to saving energy in the production of foodstuffs through targeted cooling and air conditioning of only those areas where it is required, without negatively influencing the quality. A total of six partners from the food industry, plastics and energy sectors are participating in the project. The BMWi is funding the project with around 5.3 million euros.



Schematic diagram for the Smart Consumer joint project

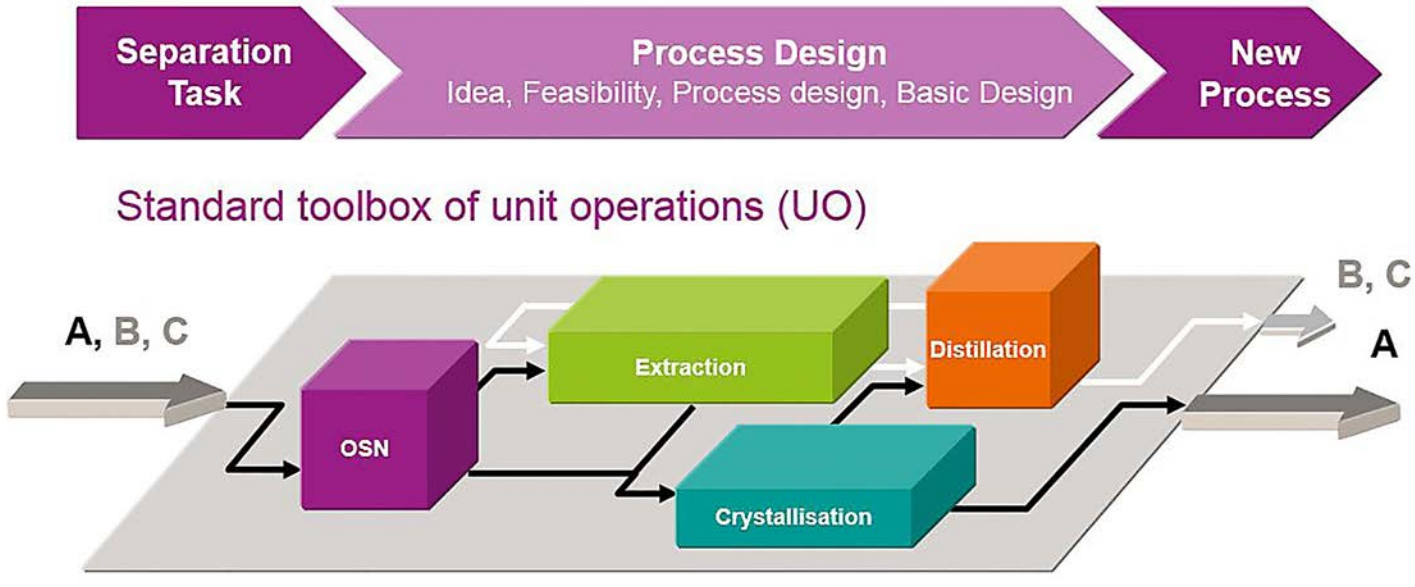
HIGHLIGHT

Energy efficient separation of substances through organophile nanofiltration

A thermal separation process is often used in the recycling of chemical and pharmaceutical products. These processes are still very energy intensive – despite the further development of the apparatus and the intelligent networking of the technologies. Therefore, this process often accounts for the main proportion of the energy consumed in the production processes.

Scientists in the **ESIMEM** project are conducting research into solutions for the energy efficient separation of substances in the chemical and pharmaceutical industries using membrane processes. The researchers aim to achieve this through organophile nanofiltration. The process uses pressurised membranes that are selective at a molecular level and hence can be used to separate substances. The advantage of this approach is that the process can be carried out without phase changes and also at lower temperatures. This results in a lower energy demand than thermal processes and the substances can be separated with greater conservation of the products.

Membrane separation processes offer significant potential for saving energy and CO_2. Although suitable membranes have already been developed, they are only employed in practical use for individual and special applications. This is because there has not been sufficient research into the characteristics and properties of the separating behaviour of the membranes in order to design a production process. As a result of this lack of basic knowledge, their potential has either not yet or only partially been exploited so as not to endanger the quality of the process and product. In the ESIMEM project, the scientists now want to provide access to this



innovative and highly efficient technology by systematically compiling and testing the required basic knowledge and tools. In order to achieve this, the researchers need to define the testing procedures and measure the characteristic properties of the different types of membranes so that they can, amongst other things, make reliable statements about their selectivity, pressure loss, material resistance and service lives of the particular membrane for a process. In addition, the aim is to carry out systematic investigations into the development of simulation and design tools.

The project partners anticipate energy savings in separation processes of between 20 and 60 percent through the use of organophile nanofiltration. The project will thus make an important contribution to improving energy efficiency in the industry. The project is being coordinated by Evonik Resource Efficiency. This project emerged from the Process Net initiative "Wanted Technologies" as a joint collaboration between industry and universities. Two research centres and three universities, as well as two industrial companies and one pharmaceutical company, are also participating in the project. The BMWi is funding ESIMEM with around 1.3 million euros.

Process of energy-efficient seperation with organophile nanofiltration

Testing of a virtual power plant with mini and micro CHP systems

In the **Regional Virtual Power Plant** project, a pilot regional power plant based on mini and micro-CHP technology is being created. Scientists at the Technische Universität Dresden are planning, building, operating and monitoring the power plant in cooperation with the energy supply company EWE based in Oldenburg. The virtual power plant will be realised using trading and operating software. The project partners are testing and developing management and control technology concepts (hardware and software) for the intelligent operation of this type of combined CHP system. In doing so, the researchers are building on the results of theoretical research into a virtual power plant from a predecessor project.

In addition, heat management in buildings will also be taken into account. Furthermore, the scientists aim to achieve a greater level of freedom for the flexible management of the operation of the virtual power plant using suitable storage systems in combination with forecasting tools. The aim is to link the electricity and heating markets at a regional level in order to make savings in the consumption of primary energy

The goal of the project is the simultaneous and system compatible integration of a variety of regionally available renewable energy sources and other efficient energy generators into the system. The project has been designed in such a way that in principle it is technologically neutral, meaning that all energy generation units can be integrated through it. In addition, the researchers want to exploit synergy effects between the technologies using a cross-system approach (building, heat, storage, electricity). The consortium is thus making a valuable contribution to reducing energy consumption for local authorities and to improving the efficiency and cost-effectiveness of mini/micro-CHP systems in buildings and distribution grids.

The project is being coordinated by the Technische Universität Dresden. The BMWi is funding this project within the EnEff:Wärme research initiative with around 1.3 million euros.

Electromobility

The German Federal Government has set itself the goal of bringing one million electric vehicles onto the German streets by 2020. The aim is to make Germany the leading market for and leading supplier of electrically driven vehicles. Electromobility forms part of the energy transition in transport and an important component of an environmentally friendly, energy efficient mobile future. Electric cars are quiet, economical and are emission free in the local environment.

Market developments in Germany and across the world

The variety of electric vehicles currently already ranges from small cars to sports cars. There were 29 series-production models from German manufacturers on the market at the end of 2015 and more are due to follow. No other country has so far been able to deliver such a broad offer of products. Germany should thus experience a sharp increase in sales in the coming years due to the continuously growing variety of models. In comparison to other important automobile nations such as the USA, China, Japan and France, Germany has established a good starting position in this competitive environment. There are currently 45,000 electric cars registered in Germany: They accounted for 0.3 percent of new registrations in 2015. By way of comparison: In Norway, the figure stands at 25 percent. In order to improve acceptance and the image of electric cars in Germany, the Electromobility Law came into force in June 2015. The law allows for electrically driven vehicles to be given special rights amongst road traffic, such as special parking spaces at charging stations, free parking spaces or the possibility of driving in bus lanes.

Progress in research and development

In order to remain internationally competitive in the area of electromobility, it is necessary to reduce the cost of electric cars and increase their performance. These are the main challenges that both the industry itself and the scientific environment supporting it are working on with a great deal of motivation: “Double the range for half the price” is the motto. Researchers are convinced that battery technologies will have significantly improved by 2020 so that electric cars will soon be able to handle more than just the commute to

work – without always having to think about where the next charging station is located. One example worthy of mention in the area of high energy lithium batteries is the recently concluded joint project **Alpha-Laion**, which has received funding from the BMWi totalling around 12.9 million euros since it started in 2012. Industry and science are building on this work and currently conducting research in the **LiMo** project into production processes for a next generation of batteries. Another flagship research and development project is the **NEXHOS** project (also see "Lightweight next generation high voltage battery units", page 116). This project is carrying out research into how lightweight high voltage battery units should be constructed in order to meet all the requirements of passenger cars. In the **DriveBattery2015** consortium (also see "Intelligent control and switching concepts for battery systems", page 117), the researchers not only aim to improve the range, power density, reliability and service life but also the safety of the systems.

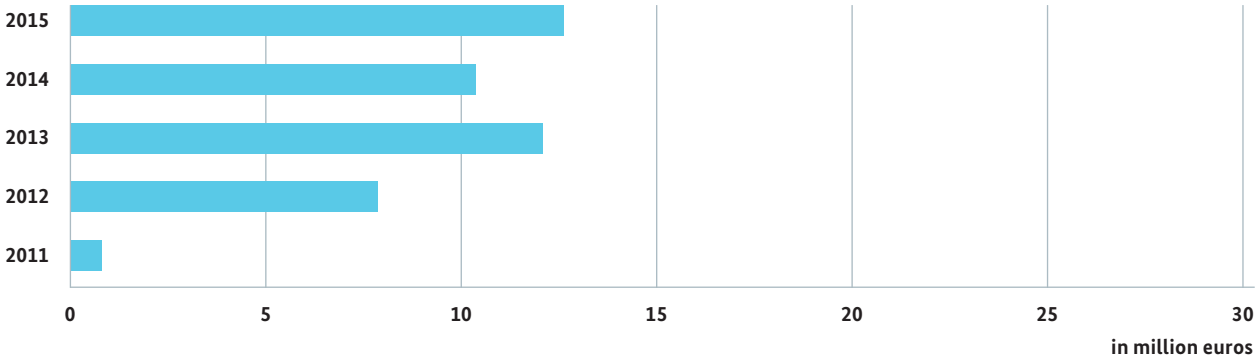
A total of 12.6 million euros of funding was provided by the BMWi for energy research in the area of electromobility in 2015 (2014: 10.4 million euros) for a total of 57 projects. There were 25 newly approved projects in 2015 (2014: around 14.9 million euros) with total funding of around 17.4 million euros over the entire lifetime of the projects.

Strategy for the research funding

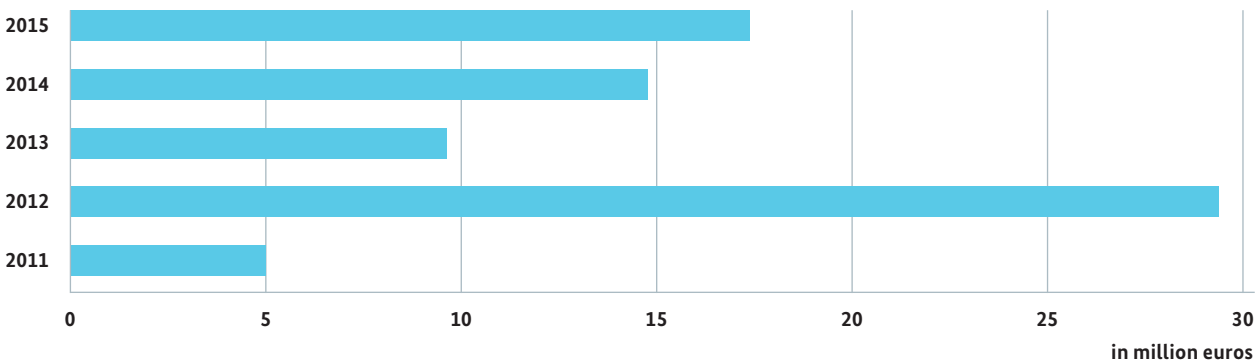
In Germany, all of the stakeholders involved with this technology have created a solid basis over the past few years for the favourable development of electrically powered vehicles.

In order to help electromobility make a breakthrough, new vehicles will require numerous technologically innovative components and systems. In line with its responsibilities, the energy research funded by the BMWi places its main

Electromobility: Distribution of funding between 2011 and 2015



Electromobility: Trend in the volume of newly approved funding since 2011



focus on the traction battery and it is also represented on the corresponding bodies of the National Platform for Electric Mobility (NPE). Related themes include the development of technologies for the charging infrastructure and its integration into the electricity grid. To make the start of the new age of electric mobility successful, another interesting aspect aside from how batteries in electric vehicles draw power for propulsion from the electricity grid will be how they can feed it back into the grid when they are, for example, parked at home and there is too little renewable power available in the electricity grid (keyword: smart home). As buffer storage systems are also required for this purpose, further synergies between the development of mobile and stationary storage systems will be created.

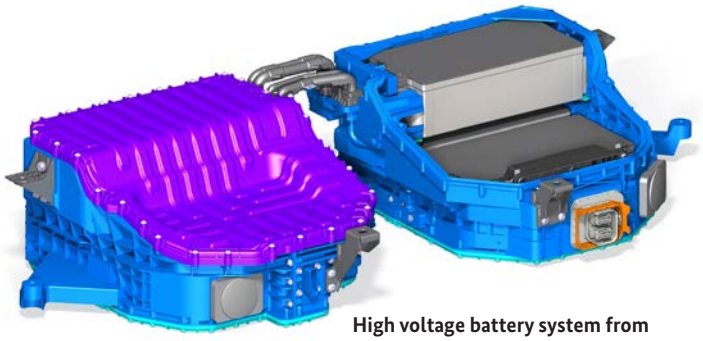
In Future, it will not be sufficient to simply have a technically superior cell, it must also be possible to produce it economically. The costs of the energy storage system, in particular, will be the most important market-related factor for making electromobility viable in the future over the long term.

An electric car at a charging station

Selected funded projects

Lightweight next generation high voltage battery units

The main challenges when it comes to the market success of high voltage energy storage systems for electric vehicles are energy density and costs. In the **NEXHOS** project (Lightweight next generation high voltage batteries) a consortium coordinated by BMW is conducting research into a new concept for lightweight lithium-ion high voltage battery systems.



High voltage battery system from the NEXHOS research project

The focus is being placed on the development of lightweight innovative materials, the associated production technologies and a battery design that will guarantee the optimal functionality of the components. Another focus is the systematic optimisation of the functionality of the entire system. The goal is to utilise a new storage concept with plastic housing components that fulfil structural tasks and act as a prototype for process and component kits for future plug-in and BEV vehicles. Another core theme is increasing the level of automation in the assembly of high voltage batteries as this offers significant scope for cost saving in relation to the current process steps that are completed manually.

The project partners are covering almost the entire value added chain with their research work to achieve the optimum cost-benefit ratio without losing touch with current development approaches. The scientists want to demonstrate a clear improvement in weight and functionality by using multiple battery components with the goal of determining the potential in production costs through the use of innovative technologies and highlighting the cost reduc-

tion potential for the key components in electric vehicles. Seven companies from the automobile, chemical and electrical engineering sectors, one university and a research institute are participating in this joint project.

The BMWi funded this project with around 9 million euros.

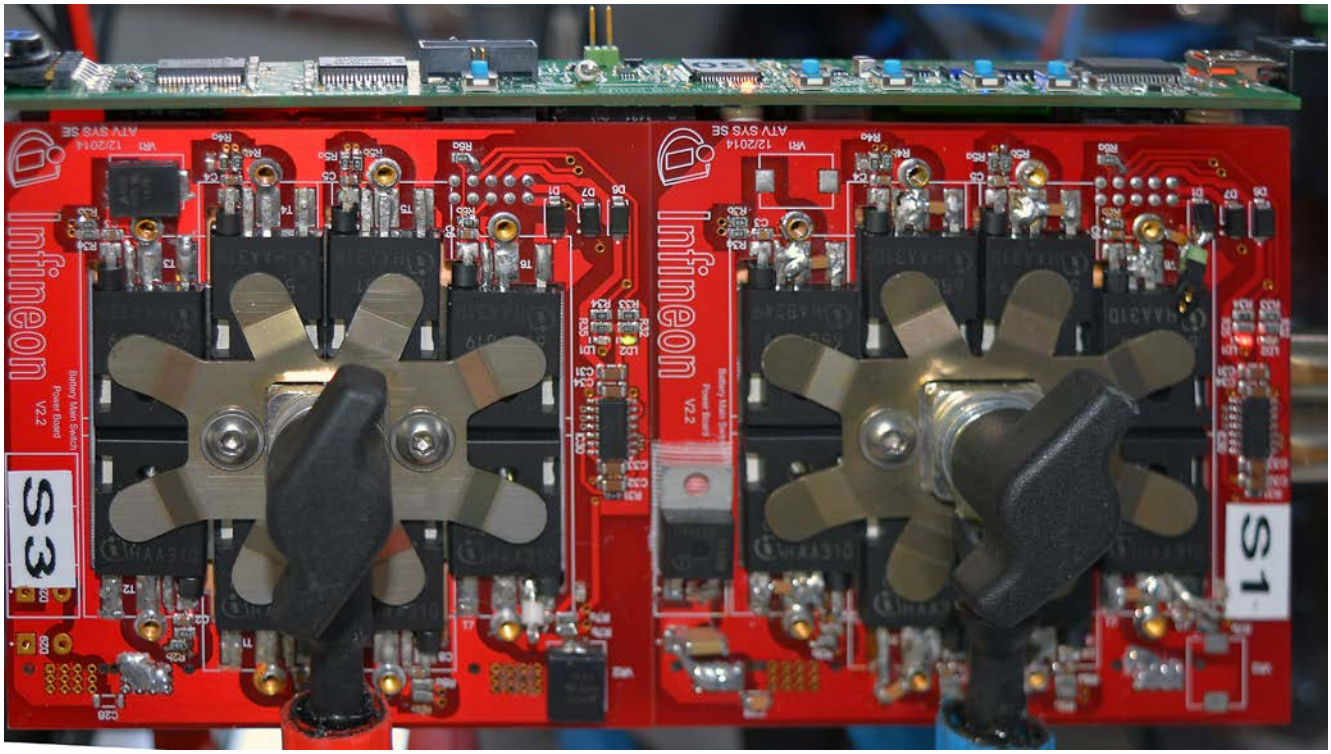
Intelligent control and switching concepts for battery systems

The battery is the decisive component in the electrification of the drive system in vehicles. A consortium within the **DriveBattery2015** project have set themselves the goal of developing intelligent control and switching concepts for multi-cell and modular battery systems which will represent another important developmental step. In this way, the scientists aim to further improve the safety, range, power density, reliability, lifespan and not least the cost structures of the systems. The joint project is being coordinated by Infineon Technologies. In total, three universities and nine industrial partners are participating in the project. The project has been subdivided into two phases. The first phase has already been completed.

A concrete example of the results of phase 1 of the project is the conceptual version of a battery master switch based on semiconductors (see image). In comparison to standard mechanical switches, this switch can turn off up to 1,000 times faster and thus protect the battery system against damage caused by short circuits. Other results from phase 1 of the project include the testing of switching options, balancing strategies, enhanced BMS online analysis methods, concepts for improved crash safety and the setting up of a battery test stand.

DriveBattery2015 brings together leading companies from along the value added chain – from component manufacturers through to systems suppliers and automobile manufacturers – to enable fundamental and practical innovations for systems and components. This structure should also ensure that the results flow into the development of standardised and marketable products. The BMWi is funding the second phase of the project with around 5.5 million euros.

The first conceptual version of a battery master switch from the DriveBattery2015 project



Systems analysis

The greatest challenge facing the German energy transitions is to establish secure, cost-effective and resource-efficient national electricity and heating supply infrastructures against the backdrop changing conditions. This requires an extensive depth of detailed knowledge in order to be able to understand the complex structures and interrelationships within the energy system and to derive inferences for future developments. Systems analysis uses models and simulations to provide these insights and thus indicate methodically sound paths for potential developments.

Market developments in Germany and across the world

Energy systems – whether in Germany or worldwide – are characterised by a high level of heterogeneity and complexity. Many parameters influence each other in various ways. These must be intelligently linked back together against the background of the energy transition. On both the generation and consumption side, the constantly growing number of market participants is influencing the overall structure and thus increasing the number of parameters in the system. This is a challenge that continues to grow with the redesign of the supply systems. Not only are the number of market participants and stakeholders in the system constantly growing but also the volume and types of decentralised electricity generators and energy converters, such as photovoltaic, wind or biogas power plants. In addition, the decentralised renewable energy technologies need to be integrated into this ever changing system in such a way as to allow affordable energy costs for private and commercial consumers, guarantee the security of supply and maintain the competitiveness of German companies on the global market.

The German energy transition is noticeably blurring the boundaries between generators and consumers. For example, a homeowner with a photovoltaic power plant on the roof of his house fulfils both roles at the same time because, on the one hand, he is generating electricity and, on the other, he is drawing electricity from the grid at times when solar radiation is low. There is also the fact that cogeneration (CHP) plants and those for the (decentralised) storage of electricity and heat lead to the increasing dovetailing of the electricity and heating markets (sector coupling). As a result

of the dissolution of the traditional division of roles, there is a need to keep the energy system in balance in order to continue to guarantee the security of supply in the future.

This is where the research discipline of systems analysis comes in: Using scientifically sound models, simulations and forecasts, it can contribute to the recent research by evaluating new developments and by making the influence of and the interactions between new technologies and applications more transparent and understandable. This allows reliable statements to be made about the effects of short, medium and long-term measures on the energy distribution system. On the one hand, this enables a transparent consideration of an increasingly complex energy distribution system and, on the other, simplifies future planning for the energy industry. Yet as a result of the increasing proportion of dynamic, decentralised energy plants within the whole system, there is also an increase in the demands placed on the tools used in the field of systems analysis.

Progress in research and development

In the same way as modern technological approaches, systems analysis is also constantly developing as a research discipline and is supplemented by new mathematical, economic and information technology methods. In view of the increasing complexity of the system, this research field is also characterised by a large level of homogeneity in t he data, data sources, simulation tools and models used. A major challenge today is thus to create transparency between the results of the different analyses and to improve quality assurance in scientific research. It is often very difficult to meaningfully compare models and analyses with one another, even if from a superficial point of view they deal with similar issues. Yet comparability is ultimately an important prerequisite for the believability of work in the field of system analysis and thus supports the prompt market launch of new technologies and innovative processes by helping to assess their impact on the energy system.

One example of a project that focuses on the comparability of model-based scenario analysis is the **RegMex** research project (also see "Model experiments and comparison for the simulation of pathways to a fully renewable energy supply", page 125). The scientists working on this new project want to improve the quality management of energy system models in Germany.

Uniform reference datasets, a commonly used and maintained pool of data, the joint definition of standards and benchmarks and the creation of technical interfaces between software programmes and methods are important prerequisites for delivering transparency, comparability and quality assurance in scientific research. Therefore, the Federal Ministry for Economic Affairs and Energy (BMWi) funds projects that tackle these aspects. An important project dedicated to this theme was started in 2015 called **open_eGo** (also see Highlight project, page 124). The project aims to develop a cross-grid and transparent planning tool, which will be integrated into a publicly accessible online research platform.

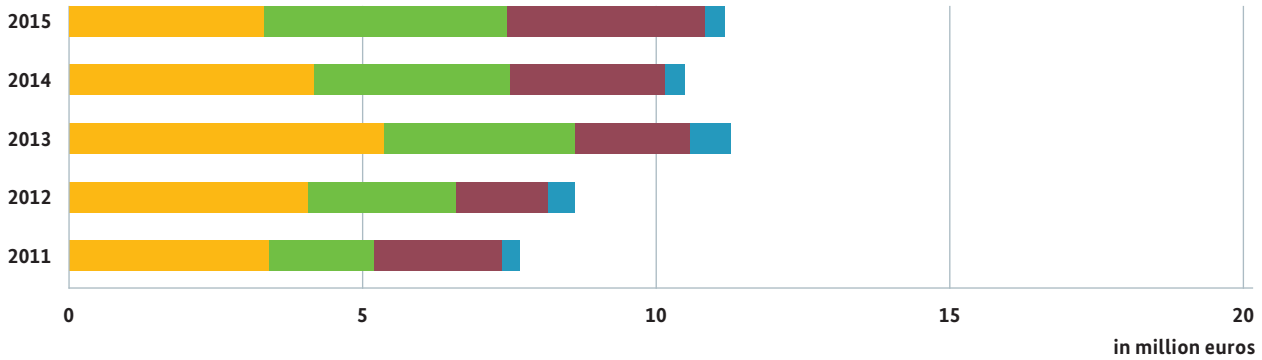
Strategy for the research funding

In December 2014, the BMWi started a consultation process to identify and deliberate on new research areas within the field of systems analysis, as well as to promote the issue of comparability and transparency in modelling results. On this basis, the Energy systems analysis research network Forschungsnetzwerk Energiesystemanalyse was established in March 2015 (also see "In Focus", page 121). The BMWi initiated this platform to substantially support cooperation and dialogue between scientists and also facilitate the exchange of ideas between the worlds of politics, research and practice.

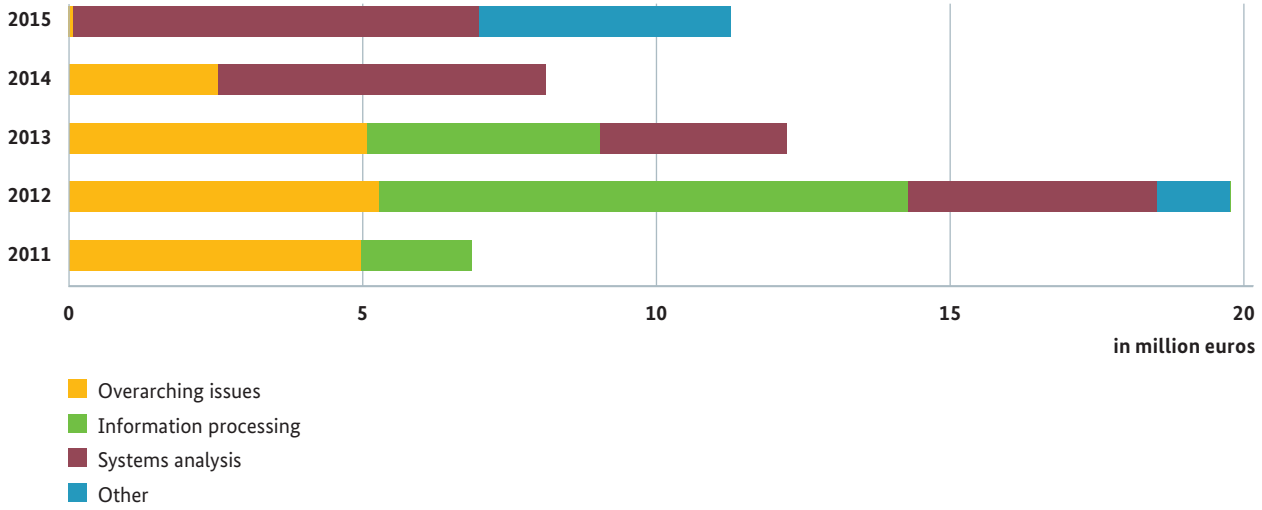
In parallel with the launch of this network, the BMWi issued a call for applications for funding in the area of systems analysis. This supplements the funding announcement by the Ministry on applied energy research from December 2014. 22 research consortiums have submitted applications for funding to the BMWi. **BEAM-ME** is the first first joint project resulting from this call and started last year. The scientists involved in the project are developing strategies for accelerating application-oriented mathematics and informatics for energy system optimisation models in order to combat the increasing complexity of models and methods that are currently used in the field of systems analysis.

Methodological and analytical research into the future design of the energy system continues to be the main focus of project funding in the area of "En:SYS-systems analysis for energy research". The research funding in this area covers engineering and economic disciplines, as well as social sciences, mathematics and information technology

Systems analysis and overarching issues in the energy transition: Distribution of funding between 2011 and 2015



Systems analysis and overarching issues in the energy transition: Trend in the volume of newly approved funding since 2011



projects. The BMWi provides support on the analysis of specialist themes including energy storage systems, electricity grids or electromobility, as well as technical evaluation, technical acceptance and the analysis of impediments.

However, a clear priority is the methodological further and new development of energy models. This includes mathematical and information technology methods, the coupling of energy sources and uncertainties. Projects dealing with the data pool or coherence between models also rate high, as do projects that develop quantitative models to simulate possible developments in the energy system and evaluate the different energy technologies from a macroeconomic perspective.

In the area of systems analysis, the BMWi funded 99 ongoing projects and approved 27 research projects in 2015. The BMWi awarded around 11.2 million euros (2014: around 10.5 million euros) of funding to ongoing projects. The newly approved projects had a total funding volume of around 11.2 million euros (2014: around 8.2 million euros). The increase in funding provided to energy research projects in the field of systems analysis is thus particularly noticeable.

IN FOCUS

The energy systems analysis research network

In early 2015, the Federal Ministry for Economic Affairs and Energy initiated a long-term research network Energy systems analysis that is designed to combine and coordinate the research activities in this area. The network aims to bring together the heterogeneous landscape of stakeholders in this research field and to intensify the dialogue between the worlds of politics, research and practice. In addition, the participants will be able to provide advice on future research strategies. The launch meeting of the network was held in December 2015 with around 120 participants.

The research network and its working groups are embedded within the context of the BMWi's "Energy Transition Research and Innovation Platform". The Federal Ministry for Economic Affairs and Energy has commissioned Project Management Jülich with the task of coordinating the network's activities and managing its members. An important goal of the network is to improve the transparency and comparability of modelling tools and to help secure quality control in scientific research. After all, the wide field of energy systems analysis, in particular, is characterised by a large number of different analysis tools.

Around 160 members have registered with the research network since it was launched in early 2015. They represent a broad spectrum of academic institutions, universities, research centres and institutions as well as companies. The work carried out by the members focusses on, amongst other topics, the themes of energy marketing and regulatory framework conditions, cross-sector modelling, cross-border and international interrelationships and sociological and socio-economic modelling. The methodological focus of the research conducted within the network is, for example, comparability and transparency, reducing complexity (through mathematics and informatics), the use of (super) computing, stability, robustness and sensitivity analyses.

The launch of the research network in March 2015 was accompanied by a call for applications for funding by the BMWi on the theme of energy systems analysis. In the two-month application period, 60 outlines for potential research projects were submitted and subsequently evaluated by Project Management Jülich. This resulted in a total of 22 research projects, of which more than a third have already been started.

The inaugural conference for the network was held at the conference centre of the Federal Ministry for Economic Affairs and Energy in Berlin on December 7th, 2015. In an open forum on a variety of themes, around 120 participants discussed the future design and structure of the research network. In addition, the event stimulated an intensive exchange of ideas on fundamental issues within the funding area.

Dr.-Ing. Rodoula Tryfonidou, civil servant for the BMWi at the launch conference of the research network on 7 December 2015 in the auditorium of the ministry in Berlin

Selected funded projects

Rebound effects in the refurbishments of existing buildings

Following the energy-related refurbishment of existing buildings, it can be assumed that there will be a significant saving in energy costs. However, these savings are often rather less in reality than predicted. The reasons for this discrepancy can be varied. One reason could be the change in user behaviour that comes with the realisation of efficiency measures. While living comfort increases, energy consumption does not fall as much as expected.

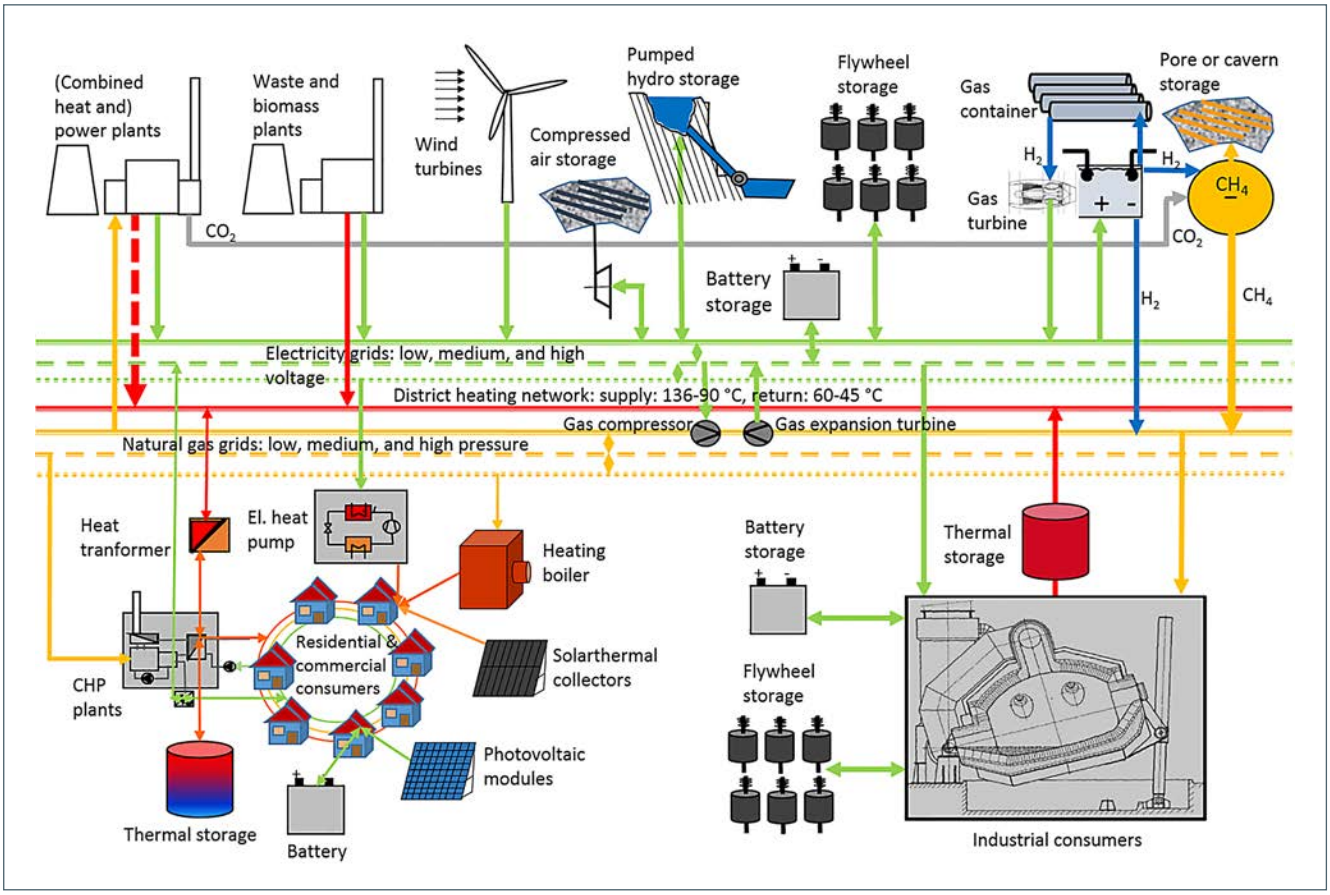
This phenomenon was investigated by the scientists at the Institute for Energy Efficient Buildings and Indoor Climate at the E.ON Energy Research Center at the RWTH Aachen University. The researchers have analysed the energy performance of existing buildings before and after they were refurbished in field tests. The focus of the research was the holistic redevelopment of three buildings from the 1950s using seven different renovation concepts. The concepts differed in the design of the insulation for the building envelope and the technical systems. In addition, high resolution monitoring systems were installed during the refurbishment work. The scientists discovered that the lower than expected energy savings were due to both technical reasons, such as installation and system errors, and social factors, such as user behaviour. The aim is now to develop coefficients and user types that can be taken into account in future calculations of the savings potential.

In parallel, the Institute for Future Consumer Needs and Behavior (FCN) at the RWTH Aachen University analysed the energy consumption behaviour of residents of energy efficient buildings. The scientists came to the conclusion that a better exchange of information between planners and users in advance and the inclusion of all interested parties in the overall process of the renovation and the development of the systems are important prerequisites for the successful implementation of energy efficiency measures in practice.

The BMWi has awarded funding of around 640,000 euros to the project on **Rebound effects following the refurbishment of existing buildings**. The Federal Ministry is funding this analysis of energy consumption behaviour with around 450,000 euros.

West façade before and after the refurbishment

Energy system model



Transient behaviour of coupled energy networks with a high proportion of renewable energies

By efficiently integrating renewable energies into the energy supply system, it could be possible to reduce both CO_2 emissions and the dependency on imported fossil fuels. This will require technical solutions for a successful energy management system.

In the **TransiEnt.EE** research project, scientists at the Hamburg University of Technology (TUHH) are developing models based on the programming language Modelica in order to identify innovative and reliable possibilities for efficiently integrating renewable energy sources into an existing energy supply structure and to maximise the self-sufficiency of the energy system.

The focus of the project is placed on the creation of an overall model for the City of Hamburg that can represent a variety of scenarios as they progress over time and thus help to create the foundations for the optimisation of the energy supply system of the city. For this purpose and based on the current status, a variety of energy supply scenarios – which differ according to the type of electricity and heating supplied (centralised or decentralised) and the proportion of renewable energies – will be modelled and compared with one another. The parameters being used in the evaluation are the annual CO_2 emissions of the city. The project team are also taking into account framework conditions such as the security of supply, economic plausibility and availability of technology.

The models developed in the project are not only applicable to the City of Hamburg but could also be utilised in future as an energy system library for other whole or partial models of energy supply systems.

The BMWi is funding this research with around 900,000 euros.

HIGHLIGHT

Planning tool for determining the optimal expansion of the grid and storage systems in Germany

Due to the fact that there are more than 800 different operators affected by the expansion of the grid in Germany, a diverse range of approaches and models must be taken into account. The area of energy systems analysis and modelling is also currently characterised by the development of proprietary models. In terms of the research being conducted with regards to grid expansion planning, this creates a lack of transparency and opportunities for the stakeholders involved to participate. This results from the lack of a suitable planning tool that is taking the optimal economic utilisation of flexibility options at different levels into account and allows the integration of all stakeholders.

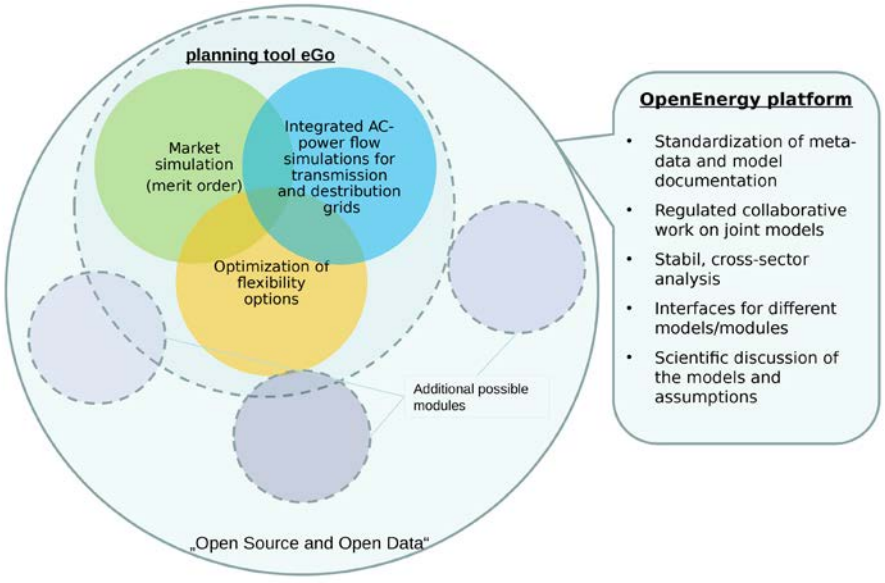
Scientists in the **open_eGo** project coordinated by the Flensburg University of Applied Sciences thus aim to develop a transparent planning tool for all grid levels in order to determine the optimal expansion of the grids and the associated storage systems in Germany. The eGo tool will then be subsequently integrated into a publicly accessible virtual research platform called the "OpenEnergyPlattform". This will also be created within the joint project. The goal is to provide a platform to assist cooperation between various participants in the energy transition from the worlds of science, industry and politics and to increase transparency. The publication of the data pool used for the calculations will also contribute to the achievement of this goal.

The project partners want to model economically favourable scenarios for the expansion of the grids that take alternative flexibility options into account, such as the use of storage systems or redispatch measures. Amongst other things, the scientists want to model the transmission and distribution grids as realistically as possible and define the future configuration and expansion of the grids and storage systems at these levels in relation to the precise location. In addition, the researchers aim to link economic optimisations and grid-related operational optimisations with one another in an innovative manner.

The project tackles current problems in grid expansion planning that are related to the energy transition and links these with the efficient bundling and utilisation of resources in the area of macroeconomic energy system modelling. In the area of grid planning, the project will contribute to further technical and economic advances in relation to the feed-in of a high proportion of renewable energies in existing energy supply infrastructures.

Alongside the Flensburg University of Applied Sciences, other participants in the project are the Reiner Lemoine Institute, the Europa-Universität Flensburg, the EWE-Research Centre for Energy Technology and the Otto von Guericke University of Magdeburg. The BMWi is funding the five partners in the consortium with around 1.8 million euros.

Goals of open_eGo



Electric cars can act as intermediate storage systems in future

Model experiments and comparison for the simulation of pathways to a fully renewable energy supply

During the course of the energy transition, a variety of different model-based scenario analysis tools for the energy system have been developed. These tools sometimes generate very different results and are thus difficult to compare. This hinders the systematic further development of future knowledge about the energy transition and complicates the process of mutual quality assurance so that contradictory statements on the long-term relevance of technologies and infrastructure-related guidelines can occur. The **RegMex** project thus aims to contribute to the further development of concepts for energy system modelling in Germany. The goal is the comparative modelling of scenarios for an energy supply system based completely on renewable energies.

Alongside promoting the growth in specialist knowledge about possible development paths for the energy system, the researchers want to advance methods for the quality assurance and comparability of quantitative energy system scenarios. They aim to create uniform categories and templates for the modelling process in order to generate meaningful and comparable results. As a result, the scientists hope to be able to better understand and evaluate differences in the statements made about the need for flexibility in future energy systems. Furthermore, the researchers want to analyse defined energy transition scenarios with a focus on selected cross-sector interrelationships and potential (inter) sectoral "lock-in" effects with different model settings in order to be able to derive robust conclusions and uncover critical aspects of the scenario analyses. The project is being coordinated by the Wuppertal Institute for Climate, Environment and Energy. Other partners are the Fraunhofer Institute for Solar Energy Systems ISE and the Institute of Engineering Thermodynamics at the German Aerospace Center (DLR). The BMWi is funding RegMex with around 420,000 euros.

Integrating electric cars into the grid as mobile storage systems

The batteries in electric cars can temporarily store excess energy from the electricity grid and feed it back into the system in periods of high demand. For this Vehicle-to-Grid (V2G) approach, the Institute of Energy and Climate Research – Systems Analysis and Technology Evaluation (IEK-STE) at Forschungszentrum Jülich is investigating various charging and discharging strategies and marketing options in the **NET-INES** project. The scientists have examined the technical and economic prerequisites for integrating mobile electrical storage systems consisting of traction batteries in electric vehicles into the grid and evaluated their use for the provision of grid services. Alongside the requirements placed on the battery and the electricity grid, the willingness of vehicle owners to make their electric car available for V2G or to sign up to a V2G contract when purchasing this type of vehicle was also investigated.

A main focus of the project was a survey of 611 vehicle owners to determine the motivation for participating in V2G. The evaluation of the survey showed that willingness generally increases when the owner is less worried about the battery not being sufficiently charged when they set off on a journey. Furthermore, interest in V2G is even higher when the owners are less worried about limitations to their freedom and independence. In addition, the researchers also investigated how much extra ageing of the vehicle battery could be expected and what contribution this type of storage could make to the stability of the grid and the integration of fluctuating energy sources. A potential business model was developed on this basis that proposes linking individual batteries to large electrical storage systems and compensating the vehicle owner in the form of premiums on their vehicle licences. The project partners also included the Center for Solar Energy and Hydrogen Research (ZSW) in Baden-Württemberg and the Technische Universität Berlin. The BMWi funded this project with around 1.1 million euros.

International cooperation

The global character of climate change requires an international response and thus makes international cooperation in energy research an important factor for the success of the energy transition. In keeping with the principle of "borderless energy", financial and scientific resources can be combined in a targeted way at a transnational level so that efficient and effective innovations for the energy system will be developed worldwide. Therefore, the further expansion of international cooperation forms a guiding principle of the Energy Research Programme.

A look at the scientific environment clearly demonstrates that international cooperation in research projects is increasingly gaining in importance. The Federal Republic of Germany thus strives at a variety of levels for more intense cross-border dialogue on climate protection and for a more forward-looking use of energy that conserves resources. The German Federal Government is therefore cooperating both at the regional and the global level with other countries for the funding of innovations in order to push forward the restructuring of the energy system. The strategy followed by the BMWi is based on close cooperation within the European Union (EU) and also cooperation in the context of the International Energy Agency (IEA).

Energy research within the European Union

The European Union and its member states are committed to providing an environmentally friendly, reliable and affordable energy supply. Innovations and their intensive funding create the foundations for achieving this goal at a pan-European level. The strategic orientation of the support for research, development and demonstration projects is defined by the SET-Plan (Strategic Energy Technology Plan). This follows an integrated approach and sets the funding priorities.

One example of the implementation of the SET-Plan is the so-called Berlin Model. The Berlin Model follows a simple process and enables the funding of joint multinational research projects with applicants from a number of different European countries. In this process, the scientists

involved in the project apply for funding from the relevant funding agency in their own country. The funding agencies then coordinate the funding between themselves accordingly. The important factor is the European dimension of the planned project. It has been possible to successfully establish several projects on the basis of this model since 2012, such as six transnational projects on energy efficiency themes from a joint funding announcement with Finland in 2013. In addition, collaborations exist with Austria and Switzerland in the fields of energy efficient cities and hydrogen and fuel cell technology. One of the projects with funding based on the Berlin Model is **Smart Planning** (also see "Integrating smart grids and the smart market into the planning process", page 128).

The basis for the funding measures for research and innovation is now the eighth EU framework programme for research and innovation – Horizon 2020. The programme runs until 2020 and is the EU's largest research and innovation programme to date with around 80 billion euros of funding. In the area of non-nuclear energy research, around 5.9 billion euros of funding are planned over the full seven year term of the programme. In this context, the European Commission publishes annual calls for proposals that can be used by research institutes, universities and companies to apply for project funding. The National Energy Contact Point (NKS Energie) advises interested applicants free of charge on behalf of the BMWi.

In order to avoid inefficiencies and create synergies between national and European funding policies, the BMWi participates in European technology platforms such as "Electricity Networks of the Future" or "Hydrogen and Fuel Cells" within Horizon 2020. In addition, the Ministry participates in so-called ERA-Nets (such as "Solar-ERA.Net", "Geothermal ERA"). In an ERA-Net, ministries and project managers coordinate and support the cooperation of national and regional research partners at an international level.

Advances in energy systems and technologies and improvements in energy efficiency can result in competitive economic advantages and export opportunities for European companies. Therefore, the EU-wide energy transition also offers an economic opportunity with positive effects on the environment and society. The involvement of business through industry initiatives on a variety of technological themes is thus an important component of the implementation of the SET-Plan.

International cooperation within the International Energy Agency

The International Energy Agency (IEA) unites 29 member states with the common goal of funding transnational answers to the most important energy issues. The so-called Technology Collaboration Programmes TCP (formerly "Implementing Agreements") form the main basis by acting as platforms for international research cooperation. They serve to promote intensive dialogue between scientists and decision-makers from all of the countries contributing in the relevant TCP. The Federal Republic of Germany is represented in 26 TCPs and thus lends the thematic areas within its funding policy measures an international quality. The energy research activities are coordinated by the Committee on Energy Research and Technology (CERT). The German Federal Government is represented on this body by the BMWi.

The BMWi encourages scientists from Germany to actively participate in the TCPs in order to generate new synergies and impetus for their own work through the dialogue with researchers and experts from across the world and to help them to identify common challenges and solutions. One example of German involvement in the International Energy Agency is the **EnOB: LowEx Existing Commercial Buildings** research project (also see "Low energy heating and cooling supply concepts for existing commercial buildings", page 128). The scientists at the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg are participating within the project on Task 47 "Sustainable Retrofit of Non-residential Buildings" in the Solar Heating and Cooling Programme (SHC) organised by the IEA.

Selected funded projects

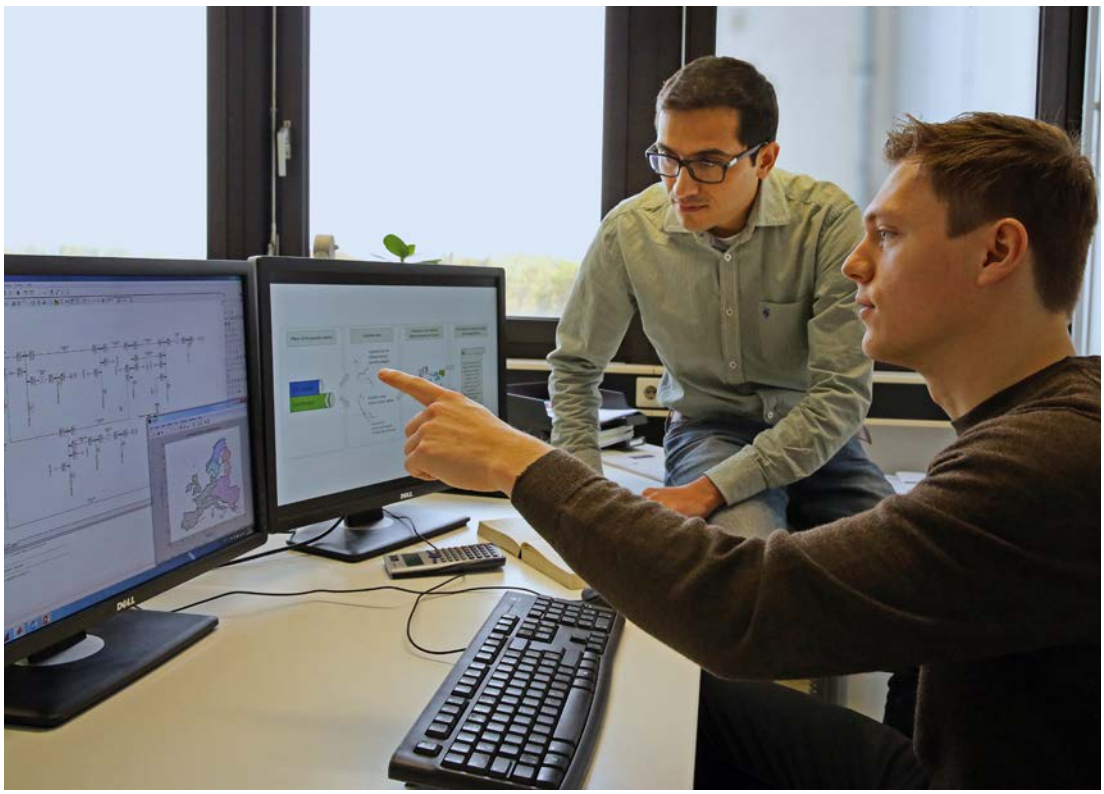
Integrating smart grids and the smart market into the planning process

Smart grid technologies have the potential of limiting the required expansion of conventional distribution grids. In addition, smart market mechanisms will create new services and value creation through the combined management of loads and decentralised electricity storage systems. The efficient development of the grid requires an optimum balance between smart market mechanisms and smart grids. The goal of the **Smart Planning** project is to take into account technological developments in the distribution grid (smart grid) and its market-related design (smart market) in the planning of the distribution grids. The scientists want to develop new methods for planning the distribution grids in an optimal and economically efficient way. The aim is to develop a balanced compromise between the added value offered by smart market mechanisms and the expansion of smart grids. In doing so, the project is also taking feed-in and load flexibilities into account. Alongside the aspects of grid planning, the scientists also want to highlight the influence on asset management.

The inclusion of European partners aims contribute to the harmonisation and optimisation of the planning basis for distribution grids within Europe. The basis for the planning process is formed on study regions in the three participating countries of Germany, Switzerland and the Netherlands. This should ensure that the results are as universal and transferable as possible. The coordinator is the Technische Universität Dortmund. In addition, further German participation is provided by the energy technology company ABB. Other partners include research teams from the Netherlands and Switzerland. Due to its international orientation, the project is contributing to the implementation of the European Union's SET-Plan. The BMWi is funding the German part of the research as part of the Berlin Model for the Set-Plan with around 720,000 euros.

Low exergy heating and cooling supply concepts for existing commercial buildings

Half of all office and administration buildings in Germany have cooling or air conditioning systems – which usually have a high energy demand. Experts anticipate a further increase in the cooling loads in future in Germany and also across Europe.



Baktash Nasiri and Christian Wagner, scientific assistants in the Smart Planning project team at the Technische Universität Dortmund

Laboratory on the Fraunhofer ISE campus with an integrated 500 cubic metre cold water storage system

Therefore, there is a need for building and system concepts that reduce the demand for energy from air conditioning solutions, without negatively influencing the thermal living comfort. Researchers at the Fraunhofer Institute for Solar Energy Systems ISE are investigating, implementing and testing new concepts for renovation, the supply of heating and cooling and the energy management of buildings in the **EnOB: Existing Commercial Building** project using typical campus buildings. For this purpose, the scientists have used an existing and a new building in a commercial complex at the location in Freiburg. Thermally optimised prefabricated façade elements with decentralised building technology systems were incorporated during the renovation process and analysed with respect to their economic efficiency and quality. Both the existing and the new building were supplied with heating using a LowEx heat pump system with a large underground cold storage system as the heat source. The scientists conducted an intensive measurement programme across the whole energy supply system with a focus on the operation of the storage system and the optimisation of the hydraulic system and heat pump. The team is participating with this research project in Task 47 "Sustainable Retrofit of Non-residential Buildings" of the Solar Heating and Cooling Programme (SHC) organised by the IEA. The results of the project will contribute to the further development and implementation of innovative concepts for the energy-related renovation and optimisation of non-residential buildings. The BMWi is funding the project as part of the funding concept "Energy-optimised construction (EnOB)" with around 1.3 million euros.

Statistical overview

Funding themes	Outflow of funds in millions of euros in					Number of ongoing projects in				
	2011	2012	2013	2014	2015	2011	2012	2013	2014	2015
Wind energy	44.01	38.42	52.57	53.06	53.04	162	209	216	242	284
Photovoltaics	38.83	51.46	48.73	43.34	59.68	204	239	241	260	262
Solar thermal power plants	6.06	7.45	8.41	9.25	10.09	53	69	70	77	75
Deep geothermal energy	11.60	20.82	17.10	15.55	13.38	90	113	123	106	94
Hydropower & ocean energy	0.49	0.98	1.25	1.21	1.68	5	8	9	15	19
Power plant technology and CCS technologies	21.22	23.00	27.82	26.74	26.22	183	208	214	233	277
Fuel cells and hydrogen	21.32	17.82	21.54	22.82	19.74	88	112	111	105	119
Storage systems	24.17	13.94	30.52	31.04	34.13	86	136	186	206	232
Grids	16.05	13.68	30.46	33.62	44.93	85	145	207	285	450
Energy efficiency in buildings and cities	31.14	42.17	52.28	55.19	51.15	313	362	398	412	486
Energy efficiency in industry, commerce, trade and the services sector	29.28	30.01	36.38	32.94	34.05	224	255	258	274	339
Electromobility*	0.65	7.82	12.07	10.40	12.61	5	24	40	44	57
Overarching issues and systems analysis	7.67	8.60	11.30	10.47	11.18	83	83	87	89	99
Total	**252.49**	**276.16**	**350.41**	**345.61**	**371.89**	**1,581**	**1,963**	**2,160**	**2,348**	**2,793**

* Electromobility was reported separately for the first time in 2015. These projects were reported under the storage systems, fuel cells and hydrogen and systems analysis sections in previous years.

Funding themes	Newly approved projects in € millions in					Number of newly approved projects in				
	2011	2012	2013	2014	2015	2011	2012	2013	2014	2015
Wind energy	81.21	78.31	36.75	38.51	85.39	68	75	56	63	103
Photovoltaics	66.43	65.43	33.99	66.91	78.64	90	80	35	90	97
Solar thermal power plants	8.89	18.02	8.65	7.44	3.76	16	25	14	22	16
Deep geothermal energy	21.44	17.43	19.21	12.65	17.33	37	29	25	15	21
Hydropower & ocean energy	0.23	3.61	0.71	2.02	2.33	1	6	2	6	5
Power plant technology and CCS technologies	26.47	30.76	27.82	23.79	53.97	44	67	64	55	108
Fuel cells and hydrogen	15.96	32.65	22.12	21.50	25.35	30	33	26	28	42
Storage systems	10.37	59.78	40.26	20.52	42.79	15	86	60	46	58
Grids	25.88	46.32	43.04	71.03	77.92	25	78	73	152	163
Energy efficiency in buildings and cities	56.74	62.38	49.48	47.19	73.48	93	112	88	98	159
Energy efficiency in industry, commerce, trade and the services sector	36.55	40.56	33.84	38.60	58.48	60	71	49	83	115
Electromobility*	5.06	29.34	9.76	14.87	17.40	7	18	12	11	25
Overarching issues and systems analysis	6.79	19.69	12.17	8.15	11.17	22	27	32	26	27
Total	**362.01**	**504.28**	**337.79**	**373.18**	**548.00**	**508**	**707**	**536**	**695**	**939**

* Electromobility was reported separately for the first time in 2015. These projects were reported under the storage systems, fuel cells and hydrogen and systems analysis sections in previous years.

Important links

www.bmwi.de
Federal Ministry for Economic Affairs and Energy

www.bmel.de
Federal Ministry of Food and Agriculture

www.bmub.bund.de
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

www.bmbf.de
Federal Ministry of Education and Research

www.bmwi.de/go/energieforschung
Energy research of the BMWi

www.ptj.de/angewandte-energieforschung
Energy Technology and Renewable Energy Department at Project Management Jülich

www.forschungsnetzwerk-energie.de
Energy research networks of the BMWi

www.forschungsnetzwerk-energie.de/gebaeude-und-quartiere
BMWi research network "Energy in buildings and districts"

www.forschungsnetzwerk-energie.de/systemanalyse
The energy systems analysis research network

www.forschungsnetzwerk-energie.de/erneuerbare-energien
BMWi research network "Renewable energies"

www.forschungsnetzwerk-energie.de/stromnetze
BMWi research network "Electricity grids"

www.cooretec.de
Research and development into future-oriented fossil fuel-fired power plants

www.forschung-energiespeicher.info
Energy storage systems research initiative of the BMWi and BMBF

www.forschung-stromnetze.info
Future-proof power grids research initiative of the BMWi and BMBF

www.eneff-stadt.info
EnEff:Stadt and EnEff:Wärme research initiatives of the BMWi – Research for Energy Efficiency

www.eneff-industrie.info
EnEff:Industrie research initiative of the BMWi – Research for Energy Efficient Industry

www.enob.info
EnOB funding programme of the BMWi – Research on Energy-Optimised Building

www.kraftwerkforschung.info
Power plant and CCS technologies research initiative of the BMWi – Research for a New Generation of Power Plants

www.bine.info
BINE Information Service on energy efficiency and renewable energies

www.enargus.de
EnArgus central information system

www.forschungsjahrbuch-energie.de
Online database for the BMWi Annual Report on Research Funding

www.foerderinfo.bund.de
The German Federal Government's research and innovation funding advisory service

www.foerderdatenbank.de
Federal database with information on research programmes from federal agencies, federal states and the European Union

www.foerderkatalog.de
Federal database with information on projects funded by the German Federal Government

www.iea.org
International Energy Agency (IEA)

www.horizont2020.de
Framework programme for research and innovation from the EU

www.nks-energie.de
National point of contact for information and help concerning all aspects of energy run on behalf of the BMWi

www.rave-offshore.de
RAVE (Research at Alpha Ventus) research initiative

www.dsttp.org
German Solar Thermal Technology Platform

www.windplatform.eu
European Wind Initiative (EWI)

www.eupvplatform.org
Solar Electricity Industrial Initiative (SEII)

www.solar-era.net
SOLAR-ERA.NET as part of the Solar Electricity Industrial Initiative

www.geothermaleranet.is
Geothermal ERA-NET

www.bmwi.de