Research for global markets – Technology partnerships for renewable energies

• The German federal government’s strategy for the internationalisation of science and research

• Off to new markets! – Renewable Energy Export Initiative

• Solar construction – Climate-appropriate construction in other climates

• Concentrating solar collectors for process heat and electricity generation

• Research on geothermal electricity generation – On-site laboratory at Groß Schönebeck

• Storing bioenergy and renewable electricity in the natural gas grid

• Solar thermal power plants – Export hits without a domestic market

• Concentrating photovoltaics (CPV) for countries with high direct irradiation

• Requirements for integration of wind energy into the grids of various countries

• Off-grid power supply and global electrification
The German federal government’s strategy for the internationalisation of science and research

In addition to the opportunities, the globalisation process also presents us with great challenges: Germany must maintain its international technological competitiveness; at the same time, it shares the responsibility for preserving global stability and sustainable living conditions. Science and research are essential for both tasks.

Germany and the European Union have set a target of investing 3% of their gross domestic product in research and development by 2010. We can only remain competitive in a world with an increasing number of competitors if we consistently work on the 3% target. In addition to the USA and Japan, China, India and Korea, as well as other former developing and emerging nations, are becoming new partners and competitors.

Against this background, the federal government developed its strategy for the internationalisation of science and research, which was passed in February 2008 and is being continued under the current government. The strategy pursues four main objectives:

- Enhancing cooperation in research with the world’s best.
- Availing of innovation potential internationally:
  This includes German companies establishing partnerships with leading international high-tech locations and R&D centres.
- Enhancing long-term collaboration with developing countries in education, research and development.

The size of the circles illustrates the countries’ share on global spendings for R&D.

Source: Batelle, R&D-Magazine, 2009 Global R&D Funding Forecast
Using the German research and innovation potential to take on international responsibility and contribute to solving global challenges.

Meeting the globally increasing energy demand with a sustainable and affordable energy supply, which protects the environment and climate, is one of the most important tasks in this context. Germany is an international leader in research and production of technologies for renewable energies and efficient use of energy. The goal of internationally-focused research must be to contribute to strengthening this leadership position and preparing the way for global use of these technologies.

However: Other countries have also identified the potential and market opportunities offered by renewable energy and are making significant investments in production and research, in particular in the photovoltaics and wind power technologies. If Germany wants to be successful in this competition, we must be better than others through our research, develop our technologies and work strategically in promoting research and the next generation of scientists, industry and infrastructure.

„Research for global markets“, as in the title of the 2009 FVEE annual conference, primarily means collaborating internationally, and doing so in a variety of ways:

Academic exchanges and collaboration with the best research centres in the world are essential if we are to retain our excellent position in research. We will only be able to continue to develop top technologies and offer them worldwide if we remain an attractive, internationally networking scientific location.

Up and coming scientists must be educated internationally and the mobility of scientists must be promoted if we are to succeed in this context.

In order to support this, opportunities for international research cooperation should be improved, internationally-focused research infrastructures should be expanded further and the presence of German universities and research institutes overseas should be enhanced. Synergies with measures and funding instruments of the European Union should be used for this purpose.
Many of the target countries for our environmentally friendly energy technology products are developing countries. However, simply exporting technology is not enough here; we also have to prepare the ground for environmentally friendly supply and usage concepts with strategically prepared cooperation projects. This includes the fostering of expertise, specialist institutions and the training of experts. This can only succeed if collaboration with developing countries in education, research and development is enhanced. Scientific and technological collaboration must complement development policy collaboration if this target is to be achieved. Important tasks in this context include initiating dialogue in international education and research, supporting research in humanities and social sciences and further developing European and multilateral instruments.
Off to new markets! – Renewable Energy Export Initiative

Renewable energy is becoming more and more important for the global energy supply. German companies in this industry have a leading position in the international competition, and their technologies are highly esteemed and in demand overseas.

The Renewable Energy Export Initiative was established in 2003 based on a decision by the German Bundestag to make an active contribution to global climate protection by distributing German technologies, and to support German companies in positioning themselves on international markets.

Since then, the initiative has been managed, coordinated and financed by the German Federal Ministry of Economics and Technology (BMWi). It is supported by Deutsche Energie-Agentur GmbH (German Energy Agency, dena), the Association of German Chambers of Commerce and Industry (DIHK) and the affiliated German Chamber Network (AHKn), Germany Trade and Invest (GTAI) and the German Society for Technical Cooperation (GTZ).

With a wide range of measures, specially tailored for the requirements of small and medium-sized companies, the Export Initiative supports the German renewable energy industry in opening new sales markets overseas:

1. Market information

At events in Germany on selected target countries, entrepreneurs can learn about potential sales markets.

In addition to this, numerous publications offer compact industry profiles and comprehensive country and market analyses. A weekly newsletter reports on the latest industry news and trends in the target markets.

2. Business development

In order to support German companies in business development worldwide, the Export Initiative offers the so-called AHK business travel programme. It involves individual travel for German entrepreneurs to potential cooperation partners and a central presentation event in the target country.

The Export Initiative organises travel for foreign potential customers or decision-makers from the fields of business and politics in the target country to Germany with the purchaser or multiplier programme. This allows them to learn about German technology on-site, and do business with German providers of products directly.

3. Programme for developing countries

By providing market information and developing contacts to local experts, business partners and decision-makers on-site, the...
Project Development Programme (PEP) assists German companies in positioning themselves in developing countries. In addition to this, the programme also supports local private-sector structures in these countries via knowledge and technology transfers.

4. Marketing support

The Export Initiative offers support for successful overseas marketing. This includes joint stands at trade fairs overseas and presentation of German renewable energy companies in the Internet or in multilingual marketing and exhibition material under the image label “renewables – Made in Germany”. In addition to this, the Export Initiative also supports the image-enhancing installation of solar energy systems on representative institutions as flagship projects overseas. The virtual marketplace www.renewablesb2b.com allows companies to make contacts around the world quickly and easily and market their products.

The economic dynamics of companies who have availed of the services of the Export Initiative have developed particularly successfully. They can save a lot of time and money when entering the market.

See www.exportinitiative.bmwi.de for further information on the services of the Export Initiative and current events.
Solar construction –
Climate-appropriate construction in other climates

If the climatic conditions in a region permanently or temporarily deviate from the range considered comfortable by users, measures must be taken to condition the interior climate to make the living environment pleasant. The task of climate-appropriate construction consists in ensuring comfortable interior conditions all year round with constructive means only, with a minimum use of fossil fuels and a maximum percentage of renewable energy.

Modern designs often ignore the fundamental climate-appropriate principles and then attempt to use high-tech systems (generally with significant consumption of fossil fuels, and sometimes with air conditioning systems which are found unpleasant) to compensate for incorrect construction physics decisions. In many countries, buildings are designed and built based on western models, even though they may already have led to construction physics problems in their countries of origin. In locations with warm external climates, the energy consumption of buildings considered unfavourable in European or American conditions increases significantly, as much of the energy must be used to cool the building. However, especially in countries in the sun belt, use of solar thermal cooling and air conditioning processes is a promising alternative to electrically powered chillers. Climate-appropriate construction, which fulfils the criteria of summer-time heat protection, can guarantee a more pleasant interior climate and save a lot of energy.

Unfortunately, architectural designs are transferred from one climatic region to another without a second thought, even if they are completely unsuitable there. The main reasons for these violations of the principles of climate-appropriate construction are historical and social:

- Historically, the inappropriate building styles were initially imposed by the colonial powers. They took possession of overseas territories and forced the construction style of their home countries on the inhabitants of the colonies against their will. For example, the building types appropriate and adapted for the climate in Holland are absolutely unsuitable for the former Dutch colony of Indonesia.

- Today, emerging countries manufacture and install technical systems in buildings which do not suit the local climate due to a naive belief in progress and a lack of knowledge of construction physics. The same applies for the uncritical application of European construction standards. Regulations which may be appropriate in Europe are not necessarily suitable for China or Taiwan. Local architecture, which grew organically over centuries in the respective climatic regions, is not appreciated or is disregarded by domestic architects. They want to be “modern” and imitate the designs considered so (e.g. glass and steel facades as built in America).

Principles of climate-appropriate construction

Depending on the climatic conditions in a region, the interior climate of a building must be adjusted in a way that pleasant conditions are provided for its users. Different comfort criteria and different measures are key for conditioning, depending on whether it is too cold or too hot outside. Figure 1 shows the step-by-step procedure for minimising the energy requirement. Step-by-step optimisation makes evaluation and prioritisation of the individual measures easier, and facilitates cost-benefit analysis.
In order to achieve the project target of minimum use of fossil fuels and maximum use of renewable energy, the following procedure is recommended:

First, the climatic conditions and the conditions due to the planned use are analysed on site. Adjusted for these conditions, the technical equipment of the buildings should be designed such that as little energy as possible is required for internal conditioning and any other requirements. While a solution optimised specifically for the local climate must be developed during planning of a building, the same potential savings may be utilised for the use-specific energy requirements as in Europe. Based on the concepts developed and taking the requirement figures of comparable premises into account, the expected overall energy requirements are determined.

In a further step, the renewable energy sources available at the project location are analysed and their suitability and economic feasibility for this project are evaluated. As a result, a recommendation of suitable systems and equipment and a mathematical estimate of the proportion of the overall energy requirement which can be supplied from renewable sources are drawn up.

Any remaining energy requirements are covered with conventional processes, whereby an environmentally sensible and economic combination with the renewable systems is the goal. This results in an optimal or multiple equivalent overall concepts for energy supply.

**1st step: Climate factors and climatic conditions**

A precise analysis of the climatic conditions on site is essential in determining the feasibility of a project in terms of energy and construction physics. Key external climatic factors which influence the energy requirements of a building are as follows:

- Temperature and relative humidity of the exterior air
- Irradiation intensity
- Wind and rain may be important if the external air or evaporation cooling are to be used to improve the indoor climate.

For apposite planning and construction, the factors arising from the local climatic conditions must be taken into account. The influences on the user’s comfort, the safety of the buildings and the premature aging of construction materials must also be analysed.
2nd step: Energy optimisation of buildings

The main adjustments and construction physics influences are shown in Figure 2.

Accordingly, for a climate-appropriate building design, e.g. for a location in the United Arab Emirates, where climatic conditions require cooling but no heating, the following measures must be ensured:

• Favourable ratio of external surface to building volume (i.e. where possible, multi-storey, larger units)
• Preferable orientation of buildings from east to west as this results in the lowest irradiation effect (due to the extremely high sun)
• Minimise window surfaces, use double and triple glazing, avoid windows facing east or west due to the strong irradiation
• Preferably automatic shading, low SHGC (Solar Heat Gain Coefficient) values of windows reduce heating by the sun
• Good thermal insulation of the roof surfaces in particular
• Lightest possible colours for the external surfaces, to reflect more of the solar irradiation and absorb less
• Decrease the exchange of air in warm periods to prevent excessive heating of the building, ventilation system with heat recovery
• Avail in full of options for nocturnal ventilation (care is needed in high humidity areas)

• Where possible, urban developments should be planned such that streets are narrow and the buildings opposite one another provide shade.

3rd step: Efficient building conditioning and technical systems

According to the project targets, renewable energy should be used to cover as much of the energy demand as possible. The potential natural or renewable energy sources must be taken into consideration and their availability and respective possible energy supply potential must be evaluated based on technical and economic criteria.

As already stated in the introduction, as much of the energy required to generate cooling as possible should be provided from regenerative energy sources. As a result of the high solar potential which is available in many cases, the use of solar energy for conditioning buildings and open spaces should be investigated first. Use of photovoltaic systems for direct conversion of solar irradiation to energy makes sense in countries in the sun belt, due to the high availability of solar irradiation. For example, the annual total irradiation in Dubai is 2000 kWh/a m². That means that standard modules can produce yields of 100 MWh per annum on a surface area of approx. 500 m². The only problematic or limiting factor for use on site is soiling via sand and dust.
There is a variety of different thermally driven processes for generating cooling and providing fresh air conditioning using (solar) heat. In general, two types must be distinguished:

- Closed systems which provide cooling for comfort air conditioning in the form of cold water
- Open processes used to condition fresh air

Which of these processes is suitable for a particular application depends in particular on the climatic conditions (irradiation, external temperature, external air humidity) on site, in addition to the building design, building use and comfort requirements. High irradiation leads to great system loads, while high external temperatures and air humidity limit the performance of the systems due to the recooling required.

Conclusion

Climate-appropriate construction largely depends on constant consideration of the prevailing climate parameters during the building design phase.

The energy required for indoor climate conditioning can be significantly reduced via simple building measures. Studies show that the potential savings in building energy requirements can reach up to 75%. To achieve this, the various measures must already be taken into consideration as part of planning:

- Climate-appropriate building design
- Use of new energy-saving technologies
- Combination of high-efficiency systems for supplying power and cooling

Constructive measures in particular can only be changed to a minor extent after the fact. The design and combination of the system technology also requires comprehensive planning, as over or undersizing leads to a significant increase in the primary energy requirement or to a lack of conditioning in the interiors. Therefore: First, build appropriately for the climate, then install air conditioning appropriate for the building!
Concentrating solar thermal collectors for global markets

Concentrating collectors are particularly suitable for generating process heat and electricity in climatic regions with high direct solar irradiation potential around the world. The earth’s so-called sun belt extends to the left and right of the equator, incorporating Southern Europe, North Africa, and the great deserts of our planet.

Collectors in the temperature range from approx. 250 °C to 450 °C are suitable for use in solar thermal power plants, such as those planned for the Desertec project. To date, thermal oil has primarily been used as the heat transfer medium in parabolic trough power plants. A future alternative is direct evaporation of water for parabolic troughs and linear Fresnel collectors, a cost-effective and environmentally friendly heat transfer medium. Smaller concentrating collectors, which generate process heat at temperatures between 150 °C and 300 °C, are suitable for solar cooling and for combined heat and power generation. This allows direct supply of industrial companies with heat/cooling and electricity. That is particularly interesting for regions with unstable electricity grids or grid-remote regions. In India alone, the off-grid electricity generation in the power range below 1 MWel accounts for 12% of the overall electricity consumption.

In Europe, approx. 27% of the overall final energy requirement is accounted for by industrial process heat. Approx. 30% of this requirement occurs at temperatures below 100 °C and a further 27% occurs in a range between 100 and 400°C [1].

Figure 1
Overview of concentrating collectors, applications and corresponding operating temperatures
A majority of process heat can be generated via solar energy. Processes with great potential for integration of low-temperature process heat up to 150 °C and medium-temperature process heat up to 400 °C are used in the foodstuffs and textile industries, for example, as well as in laundries, the metal and paper industries.

Stationary collectors for generating low-temperature process heat

One approach to utilising the great potential in the area of low-temperature process heat is the development of low-concentration stationary (i.e. do not track the sun) collectors. Compared with focusing collectors, they have the advantage that much of the diffuse solar irradiation can also be used for energy conversion. Compared with standard flat-plate collectors, they generally have significantly lower thermal losses. Therefore, these collectors are suitable for the temperature range between 80 °C and 150 °C [2]. An example for this kind of collector concept is shown in Figure 2 – the RefleC collector, developed by Wagner & Co. Solartechnik in cooperation with Fraunhofer ISE as part of a project funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

Based on the technology of standard flat-plate collectors the following goals are pursued:

- Reduction of thermal losses by using a second transparent collector cover and concentrating reflectors
- Lower costs and better draining in the event of stagnation than evacuated tube collectors
- Adaptation of the maximum collector output to the load profile of the application to be supported (via the shape of the reflectors)

Simulation results in Würzburg for the version shown in Figure 2 indicate that at a constant input temperature of 120 °C, the annual energy yield is 40% higher than for a double covered flat-plate collector due to the use of reflectors.
Direct evaporation for power plants

In generating electricity in solar thermal power plants, the system efficiency is primarily determined by the upper process temperature. Currently, a synthetic heat transfer oil stable up to approx. 400 °C is used in parabolic trough fields. A further increase of the process temperature, and thus the system efficiency, is not possible with this approach.

However, if water is evaporated directly in the collector arrays and overheated, the upper process temperature can be increased significantly. Direct evaporation of the water in the collector array is far more complex than the current technology from a process technology point of view, due to the two phase flow and the great difference in density between water and steam. The fundamental controllability of the direct solar evaporation was demonstrated successfully in the DISS test system at the Plataforma Solar de Almería (PSA) during over 10,000 operating hours.

Current development targets consist in improving key components of the collector array so that they can be used at temperatures of up to 500 °C and pressures of up to approx. 130 bar. The research efforts in this area focus on

- Absorber tubes, in which the temperature stability of the selective coating must be increased,
- Flexible pipelines, which must remain flexible at significantly higher process pressures, and
- The storage system in which economic solutions are developed for storing the latent evaporation heat.

The development work has now reached a level of maturity which encouraged German and Spanish consortia to produce initial demonstration systems. At the beginning of 2009, Novatec-Biosol commissioned the first solar thermal power plant with direct solar evaporation near Murcia (Spain). The power plant has an electricity output of 1.2 MW and uses linear Fresnel collectors (Figure 3).

Industrial process heat and combined heat, cooling and power generation

Steam is often used in industrial companies and hotels to supply heat to various consumers.
Small heat transfer surfaces and rapid heating of the connected processes are key advantages. Solar collectors can provide steam for this purpose; however, so far only a few systems have been built which use this principle. Steam is generated indirectly, oil or pressurised water is heated in the solar array and then routed to a steam generator or a pressure release. However, direct evaporation in the solar array can increase the efficiency and possibly decrease the system costs [3].

The direct evaporation is currently being demonstrated in the “Pilot solar process heat generation system with parabolic trough collectors” project. For this, 100 m² of Solitem PTC1800 collectors were installed on the roof of a production hall of the Alanod company with funding by the BMU [4]. The solar array is operated in recirculation mode, i.e. only part of the water is evaporated. The water/steam mixture is then routed to a steam drum and separated there. The saturated steam is routed to the production steam mains, as soon as a pressure of over 4 bar (abs), equivalent to a temperature of 143 °C, is reached. The water in the steam drum is pumped back into the solar array (recirculated). The evaporated water quantity is routed back to the solar array from the condensate line (Figure 4).

The combined generation of electricity and heat was studied thoroughly at Fraunhofer ISE in the “Medifres” project funded by BMU. Case studies showed that under favourable conditions in high irradiation countries, replacing diesel generators with combined solar heat, cooling and power is already worthwhile. Companies and research institutes can network on the topic of „Medium and Small Scale CSP” via the www.mss-csp.info homepage.

Summary and outlook

Concentrating collectors can make an important contribution to future solar heat and electricity supply. Concentrating collectors support the industry in decreasing their dependency on fossil fuels.

Decentralised combined heat, cooling and power can be an interesting future option. In order to establish these technologies globally, further demonstration projects are required, as well as research and development in the field of small-scale thermal engines, system integration and collector development customised for target markets, to develop concentrating collectors as an important component in future.
Literatur


Research on geothermal electricity generation – On-site laboratory at Groß Schönebeck

In Germany, geothermal heat can be provided from deeper reservoirs from depths of 400 m or more (deep geothermal energy) for large-scale heat grids and for electricity generation – combinations are also possible.

The technologies for use in deep geothermal energy generally require at least one production borehole and one reinjection borehole, which access water with sufficient temperature from a deep geothermal reservoir as required. The thermal water circuit is closed above ground, the energy is generally transferred to the respective consumer via a heat exchanger, and the cooled water is returned to the reservoir via the reinjection borehole (Figure 1).

The geothermal resources available in Germany consist of deep hot water (hydrothermal systems) to a lesser extent, and to a far greater extent of thermal energy stored in plutonic rock (petrothermal systems).

Hydrothermal systems are deep strata which carry water (aquifers) with sufficient natural hydraulic conductivity (permeability). In addition to the temperature of the aquifer, the key for economic operation of hydrothermal systems is the pump rate which can be achieved. For reasons of economy, hot water production of at least 100 m³/h is often required. While a specific temperature can always be reached at a corresponding depth, the second condition considerably restricts the number of possible locations.
Accessing these hot aquifers primarily involves a discovery risk. While the reservoir depth and temperature can be predicted relatively precisely, the main risk is insufficient aquifer permeability and thus insufficient thermal water production.

In petrothermal systems, geothermal energy is collected from plutonic rock strata irrespective of the hydraulic properties of the geothermal conductor. While the temperature distribution in the earth’s crust is prescribed by nature, petrothermal systems can improve the flow conditions to the borehole via engineering processing with engineered geothermal systems (EGS) technologies. Figure 2 shows the result of such a treatment based on the example of the on-site geothermal laboratory in Groß Schönebeck. In special cases, such treatments can be used to generate an artificial heat exchanger underground, from which the deep geothermal energy is withdrawn with surface water. In this way, petrothermal systems can increase the economy of geothermal energy generation. For example, the hydraulic fracturing or acid treatment methods can artificially increase the hydraulic conductivity even in low permeability rock. In Germany, approx. 95% of the geothermal potential can only be accessed using this technology. All system components required for this are available, but only a few projects have implemented this technology to access a deep geothermal heat source.

Access to deep geothermal energy via boreholes and the subsequent provision of energy are largely dependent on two conditions: First of all, the temperature should significantly exceed 40 °C for heating or 100 °C for electricity generation.

On the other hand, a sufficient flow rate per borehole or pair of boreholes must be attainable.

These and other basic conditions generally cannot be proven until the project development is already underway, which means that a series of decisions must be made on the way to
geothermal energy provision. Much research is still needed. The need for research for the corresponding project phases is shown by the fields with green backgrounds.

Systems for supplying heat to many or large-scale consumers, e.g. for feeding into large-scale heating grids of up to 40 MW (commerce, apartment buildings), use deep geothermal energy from boreholes approx. 2-3 km deep and feed the thermal energy into heating grids. In Germany, they currently have a total capacity of approx. 150 MW and a broader market introduction is imminent. The expansion of low-temperature heating grids would significantly expedite the market launch. Compared to smaller systems with shallow geothermal energy, these systems are more suitable for dense development.

To generate electricity, hot water is pumped from boreholes at depths of up to 4-5 km. In general, subterranean engineering work on the geothermal reservoir is required in Germany to achieve the flow rate required for economic use. Above ground, the thermal energy of the pumped hot water is converted to electricity via secondary circuits (ORC or Kalina). The first systems of this type connected to the grid in Germany, with roughly 7 MW of installed electric capacity, prove the fundamental feasibility of this type of electricity generation.
1. Storing renewable energy for fluctuation compensation, supply security and grid stability

The goal of future energy systems is a sustainable complete supply based on renewable resources. The final energy sources electricity, heat and fuel should be available at all times without usage restrictions. However, many renewable energy sources, such as wind power and solar energy, provide energy in a fluctuating manner. Energy storage is the solution. Thus, even in times when renewable energy is in short supply (e.g. no wind), the demand can be met.

This paper presents a new approach for seasonal storage of renewable energy. The storage medium in question is SNG – Substitute Natural Gas –, which can be generated via the conversion route “Biogas-to-SNG”, “BioSyngas-to-SNG” and the new “Wind-to-SNG” concept.

Generation of substitute natural gas (“biomethane”) from biogas is state-of-the-art. Manufacturing processes from biosynthesis gas via biomass gasification are currently in the demonstration phase. The process of generating substitute natural gas from CO₂ and H₂ is new. Fluctuating electricity from renewable energy sources (e.g. from wind power) is used for electrolytic generation of hydrogen, which is converted to methane with CO₂ (e.g. from biogas) or with CO/CO₂ compounds (e.g. from the product gas of the thermo-chemical conversion of biomass) in a synthesis reactor in the wind-to-SNG concept.

Using the existing natural gas infrastructure, the renewably produced, chemical energy source methane is stored efficiently, distributed and made available for use as required. Bidirectional convertability of electricity and gas facilitates energy storage and electricity grid stabilisation, by providing negative balancing energy if there is surplus electricity by feeding substitute natural gas or by providing positive balancing energy if there is a demand for electricity via conversion of substitute natural gas into electricity.

2. Energy storage: A key component in a sustainable energy system

Of all the renewable energy sources, biomass is the easiest to store, as this exists in material form as fuel. It can be stored seasonally, and is available when required for generating heat, electricity and fuel and therefore suitable for base load coverage. Biomass currently covers approx. 10% of the global energy demand. However, the contribution to global energy consumption could increase to max. approx. 20%. Geothermal energy and run-of-river hydroelectricity, other sources with limited supplies, are also suitable for covering the base load. The great potential of renewable energy sources lies in virtually unlimited solar radiation and in wind energy, although both occur in a highly fluctuating manner and can only be controlled to a limited extent, and therefore require storage.

Only sufficient energy storage can ensure a secure complete supply based on renewable energy sources. The potential and the possible fields of application of the various storage systems depend on the required storage capacity and storage duration, as well as the conversion losses and the costs. Only the expansion of the electricity grids, the bundling of different
electricity generators together with consumers and new storage concepts, along with clever management of generation, loads and storage, allow an energy system based on renewable energy sources to be created which can guarantee complete supply at all times.

2.1 Storage options for renewable energy

Most renewable energy is converted to electricity in a transportable form. However, electricity can only be stored directly to a limited extent (e.g. in capacitors). Electricity storage technologies therefore use the following forms of energy:

- Electric energy (supercapacitors)
- Potential energy (hydropower, pumped storage power plant)
- Mechanical energy (compressed air reservoirs, flywheel energy storage systems)
- Electrochemical energy (batteries)
- Chemical energy (fuels)

Pumped storage power plants are generally used for storing electricity for periods ranging from several hours to several days. In the energy industry, such hydroelectric power plants have for decades been the storage medium of choice for intermediate storage of excess electricity and for feeding these capacities back into the electricity grid when needed (peak load coverage). As their existing capacity and expansion potential are strictly limited by geographical factors and environmental conditions in Germany, they will only be able to contribute to the future integration of renewable energy into the electricity grid to a limited extent.

Compressed air reservoirs operate with output ranges similar to those of pumped storage power plants. However, there are as yet only two systems in operation worldwide.

Storage in flywheel energy storage systems or supercapacitors is limited, particularly with regard to duration and capacity. Therefore, they are primarily used for short-term (<< 1 hour) provision of power to compensate for fluctuations.

Stationary and mobile batteries represent a medium-term (< 1 day) power reserve, although their use is limited by their very low energy and power density and lifetime. The integration of future electric vehicles’ mobile batteries into the electricity grid as part of a so-called „vehicle-to-grid” concept makes it possible to charge vehicles’ batteries (energy storage) and systematically feed the energy back into the power grid. This creates large-scale “virtual battery storage”. However, its use is restricted by the availability period of the vehicles and the capacity provided by the vehicle owner. Also, intelligent management of the charging and discharging processes is required (smart grid).

For long-term storage and seasonal balancing of renewable energy sources, currently only chemical secondary energy carriers can be used, such as hydrogen and carbon-based fuels (e.g. substitute natural gas), which can be created from various renewable energy sources. The withdrawal capacities of underground gas storage including conversion to electricity extend into the 10-GW range, with cycle times ranging from days to months (see Figure 1). They therefore represent the only conceivable option for seasonally storing renewable energy with a capacity in the TWh range and converting it back into electricity when required. In addition, the chemical secondary energy carriers can be used in other application areas, such as in transport.

Figure 1
Discharge time and storage capacity of different electricity storage systems
2.2 Storage capacities in today’s energy system and when expanding electrification

In today’s energy system, energy reserves are provided via the storage of fossil fuels (coal, crude oil and natural gas). The amount of energy thus stored is typically enough to cover several months’ consumption. However, this does not apply to electricity. Supply and demand must always be precisely balanced. If supply is largely provided from renewable energy sources, the principal question is: Which storage systems can take the place of fossil fuel reserves?

The figures in Table 1 illustrate the problems with storing electricity: Generation and consumption must be simultaneous. The available electricity storage capacity adds up to just 0.04 TWh, i.e. the available storage facilities could theoretically satisfy Germany’s entire electricity demand for less than 1 hour.

If electric vehicles’ batteries are bidirectionally integrated into the grid and coupled with intelligent energy management, both the charging and the withdrawal of energy are possible (vehicle to grid). Batteries have the advantage of a very rapid response time and can thus be activated and deactivated flexibly. Therefore, these mobile energy storage systems offer the option of providing system services for grid stabilisation, e.g. balancing energy or load balancing. In peak load periods, this energy is available via discharging the traction batteries, which are then charged again during low load periods. This smoothes the electricity load curve and reduces the load on the energy generators, as well as on the grid, depending on the spatial distribution of the storage systems. Assuming that 40 million vehicles are all simultaneously connected to the electricity grid and that each vehicle feeds in 10 kWh, the storage coverage amounts to around 6 hours and is thus many times higher than the capacity installed to date in the form of pumped storage power plants (Table 2).

By incorporating traction batteries, electrification can thus make a contribution to electricity storage and electricity grid stabilisation. Therefore, in the future it will be possible to use electric vehicles primarily as short-term energy storage systems in order to support grid operation and to bridge short-term fluctuations. However, the existing system does not permit multi-day, let alone seasonal electricity storage, even under the assumption that all current vehicles were replaced by electric vehicles.

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### Table 1

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<thead>
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<th></th>
<th>Electricity</th>
<th>Natural gas</th>
<th>Liquid fuels²</th>
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<tr>
<td>Consumption</td>
<td>[TWh/a]</td>
<td>615</td>
<td>930</td>
</tr>
<tr>
<td>Average output</td>
<td>[GW]</td>
<td>70</td>
<td>106²</td>
</tr>
<tr>
<td>Storage capacity</td>
<td>[TWh]</td>
<td>0.04³</td>
<td>217⁴</td>
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<td>Mathematical storage coverage⁶</td>
<td>[h]</td>
<td>0.6</td>
<td>2000</td>
</tr>
</tbody>
</table>

1) Petrol, diesel, kerosene  
2) Fluctuates greatly seasonally  
3) Pumped storage power plants  
4) 47 underground gas storage systems (plus 79 TWh under construction/in the planning stage) [1]  
5) Stock of petrol, diesel, kerosene und extra light heating oil  
6) Relative to the average output

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### Table 2

<table>
<thead>
<tr>
<th></th>
<th>1 million electric vehicles</th>
<th>40 million electric vehicles</th>
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</thead>
<tbody>
<tr>
<td>Consumption²</td>
<td>[TWh/a]</td>
<td>1.9</td>
</tr>
<tr>
<td>Percentage of electricity consumption</td>
<td>[%]</td>
<td>0.3</td>
</tr>
<tr>
<td>Storage capacity³</td>
<td>[TWh]</td>
<td>0.01</td>
</tr>
<tr>
<td>Mathematical storage coverage⁴</td>
<td>[h]</td>
<td>0.15</td>
</tr>
</tbody>
</table>

1) Reference year 2008  
2) 0.16 kWh/km; 12,000 km/a  
3) Available storage capacity per vehicle: 10 kWh  
4) Relative to the average output of 70 GW (cf. Tab. 1)
Current knowledge suggests that the production of secondary energy carriers is a necessary prerequisite for seasonal energy storage. Liquid and gaseous fuels, unlike electricity, can be stored directly and in large quantities. In the fuel market, petrol and diesel are stored for months at a time. The gas storage capacities in Germany are around 5000 times higher than the capacities of pumped storage power plants (Table 1). As natural gas can be converted into electricity in modern power plants with an efficiency of almost 60%, the obvious solution is to use gas storage capacity for the storage of renewable energy.

2.3 Capacity requirements for seasonal storage systems

One key question in the event of 100% supply based entirely on renewable energy sources is: How much storage output and storage capacity is required in the German electricity grid, to bridge longer wind lulls for example? Renewable energies used for generating electricity and suitable for covering the base load include bioenergy, geothermal energy, run-of-river hydroelectricity and approx. 10% of the wind power capacity installed. Of this total approx. 18 GW of forecast output in 2050, bioenergy will account for 5 GW, geothermal energy for 4 GW, run-of-river hydroelectricity for 3 GW and the part of the wind energy output which is suitable for covering the base load will be 6 GW, calculated in accordance with [2]. At an average load of 70 GW (see Table 1) almost 20 TWh of storage capacity remains, if the remaining output of approx. 50 GW is drawn over a period of 2 weeks. However, only 0.04 TWh are currently available in Germany for electricity in pumped storage power plants. For complete supply based on renewable electricity, storage capacities would have to be increased by a factor of around 500!

The only viable option in Germany for the required capacities of around 20 TWh would be chemical energy carriers, which can be stored underground in caverns as gas, for example. In comparison, a reservoir cavern with hydrogen as the chemical storage medium has around 10 to 100 times the storage capacity of the compressed air variant; with renewably generated substitute natural gas, the storage capacity is even around 30 to 300 times as high (depending on the storage pressure). A comparison with existing and planned natural gas storage facilities shows that these storage capacities are already in place in the existing infrastructure (Table 1). From a purely theoretical point of view, 217 TWh of natural gas stored in caverns can be converted into 130 TWh of electricity with gas and steam power plants on a flexible timescale. There are no other storage technologies with capacities in the region of > 10 TWh on the horizon.

Nevertheless, a conflict is arising with regard to the storage of renewable energy in underground storage facilities: the technologies of compressed air reservoirs and gas storage facilities (natural gas, substitute natural gas or hydrogen) are competing with the so-called „storage“ technology CCS (carbon capture and storage), which actually refers to disposal of CO₂ and not storage of energy itself. If the large-scale conversion of fossil fuels into electricity were to involve the dumping of CO₂ in empty natural gas underground storage facilities, the corresponding reservoirs would thus no longer be available for seasonally storing renewable energy.

3. Solution: Substitute natural gas (SNG) as a storage medium for renewable energy

The renewable energy carrier SNG can be produced in a variety of ways. Primary resources include

- „Wet“ biomass for anaerobic fermentation (biogas to SNG)
- „Dry“ biomass for thermochemical gasification (biosyngas to SNG)
- Renewably generated electricity for electro-lytic production of hydrogen in combination with carbon (di)oxide from various biogenic and non-biogenic sources (wind to SNG)
- Combination of the abovementioned methods

The individual paths are explained below.
3.1 Biogas to SNG

In anaerobic fermentation of biomass, raw biogas with the main components CH₄ (50 – 70 vol.%) and CO₂ (30 – 50 vol.%) is produced. It also contains steam, minor components H₂S, NH₃, and depending on the type of pre-desulphurisation, also N₂ and O₂. Treatment of the raw biogas to SNG is implemented by removing water, the minor components and the main component CO₂, until it reaches the quality required for feeding (substitute gas quality) for the maximum concentration of the gas components and the combustion properties. CO₂ is removed in existing plants via pressure swing adsorption or various scrubber systems. The residual gas created in treatment is generally used to generate heat for the fermenter in a burner or in a gas motor for combined electricity/heat generation.

3.2 BioSyngas to SNG

If solid fuels are not burned but gasified, the result is a combustible gas which can be used for a variety of purposes. The fuel reacts with air, oxygen and/or steam, and the raw gas required is created. Its composition depends on the gasification method, the process conditions and the materials used. Ideally, the gas is not diluted with nitrogen, an inert component (gasification with air). Main components include H₂, CO, CO₂, H₂O and (depending on the gasification temperature) CH₄. Minor components such as sulphur compounds, ammonia, tars and dust loads must be removed from the gas.

To create SNG via biomass gasification, the AER (Absorption Enhanced Reforming) process developed at ZSW has ideal properties for downstream methanation due to its high H₂-content of > 60 vol.%. In this reaction, CO and CO₂ are converted to methane via the hydrogen present in the gas (Equation 1 – 3). This requires a defined H₂/CO/CO₂ ratio, provided no gas conditioning/gas separation is required. Thanks to its configurable stoichiometry [3], its components and the CH₄ part already present, the AER product gas is ideal for creating SNG, as no other process steps are required after primarily quantitative conversion and after separation of reaction water. If synthesis gases from gasification with non-adjusted H₂-content are used, downstream CO₂ separation is absolutely necessary.

3.3 Wind to SNG

The „Production of C-based fuels from CO₂ and H₂“ topic has been the subject of research at ZSW since the end of the 1980s with the objective of storing renewable energy [4 – 6]. New aspects of the wind to SNG concept are the use of existing gas grid infrastructures for storing and converting the generated fuel to electricity, and in particular the use of wind-generated electricity, the further expansion of which is currently restricted by the capacity of the electricity grids. However, solar electricity or any other type of renewable electricity can be used for the process.

The basic principle of the wind to SNG concept is the bidirectional linking of the existing infrastructure units (the electricity grid and the gas grid) with the goal of establishing a new way of managing loads and generation, which enables high proportions of fluctuating electricity generation from renewable energy sources to be accommodated in the energy system. To date, this link only exists in terms of generating electricity from natural gas (gas to power), but not vice versa (power to gas). The new concept is based on storing electricity which cannot be fed into the grid for reasons of grid stability, or

### Methanation reactions

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$\Delta H_k$ [kJ/mol]</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3 \text H_2 + \text CO \rightarrow \text CH_4 + \text H_2O(g)$</td>
<td>-206</td>
<td>(Equation 1)</td>
</tr>
<tr>
<td>$4 \text H_2 + \text CO_2 \rightarrow \text CH_4 + 2 \text H_2O(g)$</td>
<td>-165</td>
<td>(Equation 2)</td>
</tr>
<tr>
<td>$\text H_2O(g) + \text CO \rightarrow \text H_2 + \text CO_2$</td>
<td>-41</td>
<td>(Equation 3)</td>
</tr>
</tbody>
</table>
cheaply available electricity (e.g. at times when a large amount of wind power is available), in the form of substitute natural gas. One key goal is to enable the planning and control of the feed from wind farms. The principle is shown in Figure 2.

The concept envisages firstly using electrolysis to convert “excess” electricity from fluctuating sources into hydrogen, then into substitute natural gas in a subsequent synthesis step with CO₂ (and/or CO). The energy efficiency for this is > 60 % (kWhSNG/kWhel).

A wind to SNG system can accommodate excess wind power by initiating electrolysis and can store it temporarily as SNG in the natural gas grid. In times when less wind power is available, or when the demand for electricity is higher, the electrolysis level can be reduced by means of systematic reduction or deactivation of the electrolysis. In order to ensure that there is sufficient electricity generation power – even during periods of low to no wind – a combination of the wind to SNG system with a gas or combined heat and power plant is a suitable concept, whereby conversion to electricity does not have to be implemented at the location of the wind to SNG system.

The wind to SNG concept is also easy to integrate in the existing energy system. A particular advantage compared to other options is the use of the natural gas grid with its high storage and transport capacity. While a high voltage direct current transmission is restricted to outputs < 7 GW, gas pipelines can reach up to 70 GW. High wind power yields can be stored both seasonally and transported long distances with high energy transmission levels. For conversion to electricity, gas power stations with electric efficiencies of up to 60% are ideal. With an increasing amount of renewable energy in the electricity grid, Germany requires the construction of these high-efficiency power stations to be able to react rapidly to load fluctuations. By contrast to nuclear and coal-fired power plants, gas power stations can be regulated quickly and easily.

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**Figure 2**

Wind to SNG concept for bidirectional coupling of the electricity and gas grids with a link to the mobility consumption sector

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CCPP: Combined Cycle Power Plant  
B-CHP: Block-Type Combined Heat and Power Station  
BEV: Battery Electric Vehicle  
FCEV: Fuel Cell Electric Vehicle  
CNG-V: Compressed Natural Gas Vehicle  
Plug-In HEV: Plug-In Hybrid Electric Vehicle; Especial: Plug-In Electric Drive Motor Vehicles/Range-Extended Electric Vehicle
Also worthy of note, is the particular degree of flexibility regarding use options of the stored energy, because not only can SNG be converted back into electricity, it can also be used in the heating market or the fuel market. The latter is of particular interest in the context of the planned increase in the proportion of renewable fuels in transport area.

The wind to SNG concept has various interfaces to the mobility area (“wind to tank” in Figure 2), as three regenerative energy carriers for vehicles can be provided:
- (Stored) electricity for battery-powered electric vehicles (BEV)
- H₂ for fuel cell vehicles (FCEV)
- SNG for natural gas vehicles (CNG-V)

The chemical energy carriers H₂ and SNG are also suitable for plug-in hybrid vehicles (plug-in HEV), with which short distances can be traveled purely electrically – H₂ or SNG are only used for longer distances via conversion to electricity in a “Range extender”.

Hydrogen from electrolysis of wind to SNG systems can be distributed via H₂ grids and be made available for mobility. On the other hand, hydrogen can also be provided via decentralised generation at petrol stations by reforming SNG using the existing infrastructure, without requiring a large-scale distribution infrastructure for hydrogen.

### 3.4 Biogas/Wind to SNG

The carbon dioxide required for methanation can be provided from a variety of sources (CO₂ separation on conversion of fossil fuels to electricity, lime/cement production, chemicals industry processes etc.). As an “off gas”, CO₂ is created when converting biogas to biomethane (CO₂ separation). As this biogenic CO₂ is not associated with climate-relevant emissions, it is particularly suitable as an educt for methanation (Figure 3.1). Alternatively, CO₂ from biogas can also be used directly without previous separation, by feeding the biogas directly to a methanation unit (Figure 3.2). The connection of a wind farm/biogas/wind to SNG system to locations where bottlenecks in the electricity grid cause delays in adding wind power is an optimal combination (e.g. in coastal areas where a lot of new offshore wind power is installed).

![Method 1: Methanation of CO₂ after separation](image1)

**Method 1: Methanation of CO₂ after separation**

**Method 2: Methanation of biogas without CO₂ separation**

![Figure 3](image2)

*Increasing the methane yield from biogas systems by adding H₂ and subsequent methanation*
In an initial technical implementation phase, the installation of a 10 MW wind to SNG system in conjunction with a biogas plant is planned, in which the biogas is methanated to SNG without CO₂ separation by adding H₂. The system is to be commissioned in 2012.

3.5 BioSyngas/Wind to SNG

In a further version, biogenic gases from thermo-chemical gasification should be used, whose stoichiometry is not adapted to the subsequent SNG generation. Addition of H₂ to the gasification gas allows virtually complete conversion of the biogenic carbon to fuel carbon. This facilitates significantly more efficient use of biogenic resources for the fuel yield. Another aspect is the use of the oxygen produced during electrolysis for biomass gasification.

4. Experimental results

At ZSW, a variety of fixed bed reactors for SNG generation up to a power class of 50 kW was built and tested. Due to the exothermic energy from methanation and the quality requirements for the gas properties for feeding into the gas grid (H₂ < 5 vol. %, CO₂ < 6 vol. %), there are special requirements for the reaction management and the reactor concept. This is taken into account in the reactor geometry, the reactor cooling concept and the activity profiles set for the catalyst packing beds.
The target is a maximum conversion level in a single-phase reactor system without requiring downstream gas conditioning. As an alternative, reactor concepts with intermediate condensation/water separation are being investigated.

A complete container-integrated wind to SNG system in the 30 kW power class was developed as commissioned by the Solar Fuel Technology company. It contains electrolysis, methanation and control electronics including a filling module for natural gas vehicles (Figure 4). The system is used to study load profiles for grid control. After completion of the test phase, the wind to SNG system will be operated at a biogas plant. The biogas will be methanated directly (without previous CO2 separation) according to process version 2 in Figure 3.

The results of SNG generation from educt gases AER syngas, CO2/H2 and biogas/H2 are shown in Figure 5. The reactor was operated with comparable operating parameters in all three cases. After a single reactor run, the concentrations remain below limit concentrations for H2 and CO2 in the generated SNG for the educt gases AER syngas and biogas/H2 after drying without further gas conditioning. For the CO2/H2 educt gas, these limit concentrations are slightly too high, but can be complied with via reduction of the gas load and/or pressure increase.

The fundamental suitability of the wind to SNG concept for energy storage and grid control was proven. With a far less complex process compared to Fischer-Tropsch or methanol synthesis, SNG can also be produced in decentralised applications, distributed via the natural gas grid, stored and used in accordance with demand.

5. Conclusion

The various methods for producing SNG from renewable energy and the use options in different consumption sectors offer opportunities for a merging of the electricity grid, gas grid and mobility energy sectors. Electricity and SNG can be converted to one another bidirectionally and have a fully-established infrastructure with seasonal gas storage capacity. Also, H2 can be created decentrally from both energy carriers, without having to rely on a widespread H2 distribution system with high infrastructure costs. The concept presented possesses the following outstanding features:

- SNG generation permits seasonal storage of renewable energy. While the storage capacity of the electricity grid is currently only approx. 0.04 TWh – with a storage coverage of less than one hour –, the storage capacity of the gas grid in Germany is over 200 TWh with a storage coverage of months.
- The wind to SNG concept can provide positive and negative balancing energy to stabilise the electricity grid (conversion of SNG to electricity and increasing/decreasing electrolysis).
- By expanding wind energy (in particular offshore), in future, high wind power levels will be available more and more often, which cannot be absorbed fully by the electricity grid, but as SNGs in the existing gas grid.
- SNG generation from CO2 and H2 is, unlike bio-SNG, not subject to surface limitation due to the cultivation of biomass.
- SNG can be produced from various forms of renewable energy (biomass, wind/solar electricity, etc.).
- Combining the resources of biomass and electricity from renewable energy allows biomass carbon to be transferred almost completely into fuel carbon, thus increasing the coverage of fuels from biomass significantly (e.g. doubling the methane yield from a biogas plant).
Literature


Solar thermal power plants – Export hits without a domestic market

Solar thermal power plants only use the direct solar irradiation, and are therefore hardly usable in Germany. Nevertheless, German companies and research institutes are among the global technology leaders. This can only be achieved via suitable international partnerships. This presentation provides details of the major international networks in this area. Examples will be used to show how German technologies and research results can be positioned on the international market.

1. Introduction

Parabolic trough collectors, which generate electricity in a conventional power plant via high-temperature heat, have been used in the Mojave Desert in California for over 20 years. For a long time, no-one emulated this success story. However, the global challenge presented by the climate change and the oil prices shock have highlighted the advantages of this technology and have led to a veritable construction boom, initially encouraged by an electricity feed-in act in Spain. Now, construction is underway throughout the earth’s sun belt.

Two different systems for large-scale solar thermal electricity generation in sunny countries are currently available:

- **Line-focusing systems**, which direct the concentrated radiation in their caustic line to an absorber tube with a selective coating, reaching temperatures of up to 400 °C in the heat transfer medium circulating there.
- **Point-focusing systems**, in which threedimensionally curved, sun-tracking individual mirrors (heliostats) direct the solar radiation to a heat exchanger (receiver), which is located at the top of a tower. These systems can reach higher temperatures than the line-focusing systems.

Both technologies aim to replace the heat generated by fossil fuels in conventional power plants fully or partially. Their attraction is that the high-temperature heat generated can be stored very cost-effective (compared with electricity) and efficiently, to allow continued operation as clouds pass or after sunset. If low quantities (<15%) of additional fossil combustion in the power plant are possible, this concept can be used to provide electricity as required with great reliability, to replace fossil fuel-fired power plant capacities fully.

Table 1
Overview of the history of German-Spanish cooperation at PSA

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>Initiation of the SSPS (IEA) and CESA projects (Spain)</td>
</tr>
<tr>
<td>1979</td>
<td>Seven countries combine to build SSPS in Almería (DLR for Germany)</td>
</tr>
<tr>
<td>1985</td>
<td>CESA and SSPS systems merge to become PSA test centre</td>
</tr>
<tr>
<td>1981</td>
<td>First solar thermal electricity generation in Europe</td>
</tr>
<tr>
<td>1987</td>
<td>Spanish-German cooperation agreement on 50:50 basis (DLR/CIEMAT)</td>
</tr>
<tr>
<td>1990</td>
<td>PSA qualifies as a large-scale European system</td>
</tr>
<tr>
<td>1994</td>
<td>First joint EU projects (DLR/CIEMAT)</td>
</tr>
<tr>
<td>1998</td>
<td>Change of the cooperation model to project-specific cooperation</td>
</tr>
<tr>
<td>2004</td>
<td>Start of cooperation between DLR/ Fraunhofer on Fresnel collectors</td>
</tr>
<tr>
<td>2006</td>
<td>PSA celebrates 25th anniversary</td>
</tr>
<tr>
<td>2007</td>
<td>First commercial electricity generation in Spain</td>
</tr>
</tbody>
</table>

SSPS = Small Solar Power System  
CESA = Central Electro-Solar de Almeria (solar tower)
2. International cooperation as a basis for technological development

The development of this technology was initiated as early as the late 1970s by the International Energy Agency (IEA) (Table 1).

Even that far back, Germany already played a leading role when DLR was commissioned to coordinate the project of building the SSPS demonstration system in Almería, Spain. After it had successfully proven that solar thermal electricity generation in Europe was possible in 1981, operation of the plant was continued as a test centre under the name “Plataforma Solar de Almería (PSA)” (Figure 1) by a partnership of the Spanish CIEMAT and DLR.

PSA developed into the European test centre where key commercial systems which were subsequently introduced on the market, were developed and tested. This benefitted Spanish and German companies in particular. At the end of the 1990s, when it became clear that the technology had not succeeded in specific market penetration, the German side had to step back its influence due to decreasing funding and since then, it has had a guest role at PSA. In the early 2000s, the indications of market penetration of the technology in Spain increased and the development was intensified again. Other German research partners, e.g. Fraunhofer ISE became involved in these activities in 2004. The Spanish feed-in act passed in 2004 led to the construction of commercial solar thermal plants in Spain, which fed electricity into the grid in 2007 for the first time.

In order to further decrease costs, however, further research and development work is required in this area. As this has always been associated with very large and expensive test infrastructure, four major European research institutes pooled their expertise and infrastructure in 2003 to form the Sollab association, which features the Swiss Paul Scherer Institute (together with ETH Zurich) and the French CNRS in addition to the DLR and CIEMAT. This facilitated improved access to the test infrastructure for German companies.

Another key to the spread of this technology to other countries in the sun belt was the IEA’s SolarPACES cooperation, which was based on the previous activities in Almería, and now comprises 16 member states (Figure 2). In this network, in which DLR performs major coordination activities, new markets, in particular in the USA, Egypt, Algeria, Australia, Italy, Israel, UAE and South Africa, were opened, which are now largely supplied by German countries.
3. Market situation and the role of the German industry

Worldwide, approx. 0.6 GW of solar thermal power plants are operated, while approximately the same capacity is currently under construction, most of it in Spain and the USA. Other projects in the 6 – 8 GW range are in development around the world (Figure 3).

In particular, German and Spanish manufacturers are dominant. In addition to the project development and turnkey delivery of solar arrays and power station blocks, German companies are leaders in production of key components such as mirrors, absorber tubes and steam turbines. In addition to this, major German energy suppliers act as investors and, in the medium-term, probably also as operators of solar thermal power plants.
4. Competitive advantages through research and development

As solar thermal power plants have no domestic market in Germany, the industry competes on international markets. Its key to success is in the delivery of superior high-tech components and the ability to provide system solutions from one source. All technical and financial risks are covered. The major German companies from the energy industry are well positioned.

The key remains that they deliver top technology and are therefore technologically always one step ahead of competitors. This is where the German research landscape and, in particular, the Renewable Energy Research Association (FVEE) come into play, which can prepare technological development and assist in industrial implementation. Four examples of this are listed below.

4.1 Direct evaporation

DLR, in cooperation with German and Spanish partners, has led the development of solar steam generation technology, in which the thermal oil in a parabolic trough collector is replaced by water or steam, since the mid-1990s. It saves investment in the expensive special oil and the corresponding heat transfer mediums, allows higher process temperatures and thus better system efficiencies.

On the DISS test system (Direct Solar Steam) at PSA, processes were identified as safely technically controllable, comprehensive component tests were performed, and simulation models and control concepts were developed and validated. Also, the most recent investigations confirmed the economic relevance of this technology.

As the next step before market introduction, the demonstration of the overall system with multiple parallel evaporation trains in the power plant-relevant scale (approx. 5 MWe) is imminent. For this purpose, it is planned to implement a corresponding pilot system with German industrial partners in the vicinity of the planned ANDA-

SOL III power plant in Southern Spain (Figure 4), which consists of one collector array of roughly 2-3 collector strings. On one hand, this collector array must be operated continuously to evaluate and demonstrate the long-term stability of the components and the every-day operability of the system. On the other hand, it will be designed so flexibly that it will permit the investigation of various operation strategies. A 5 – 15 MWh innovative heat storage system is to be integrated in this test system, and be subjected to extended operation in the power plant, to demonstrate feasibility in real operation. In the demonstration system of a Fresnel collector with the involvement of DLR and Fraunhofer ISE at PSA, direct evaporation was used and tested successfully in the last two years.

4.2 Component development and qualification

High-temperature stable efficient receiver systems are a key component for the parabolic trough and the Fresnel technology and are required by various collector companies worldwide.

With the assistance of Fraunhofer ISE and DLR, the Schott CSP Solar company developed the evacuated receiver PTR-70. With the aid of this technology, heat losses of the absorber tubes through which the heat transfer fluid flows are minimised. At an operating temperature of 380 °C, an emission level of under 7% is reached in the newest coatings. The problem of hydrogen diffusion from the thermal oil has been solved via barrier coatings and getter materials. In addition to the receivers for thermal oil, pipes with reinforced steel walls are offered for direct evaporation.
The parabolic mirrors and collector design for the SKAL-ET collector were developed by a German company, Flagsol. The curved special mirrors consist of white glass coated with silver which has a thickness of 4 to 5 mm. The mirrors are 2 to 2.8 square metres in size. The company also supplies the control systems for the solar array, a key component for operating the overall system. In linear Fresnel collectors, high-temperature stable absorber tubes are also used, which are stable up to 450 °C in air. The secondary concentrators, which consist of borosilicate mirrors coated on the front by Fraunhofer ISE, can also withstand elevated temperature loads.

With concentrating primary mirrors and parabolic trough, Fresnel and tower heliostats, the optimal focusing of the sun on the respective receiver structure is important. With highly-developed characterisation and qualification methods for the mirror components, both FVE institutes contribute to quality assurance in power plant construction. Important elements include ensuring the mirror shape, spectral reflectivity and the endurance of the components. The question of measurement and in particular the degradation of complete collector arrays requires further development of the methods used to date. Standardisation of the methods is advanced worldwide as part of the IEA Solar-Paces programme.

4.3 Operation optimisation via forecasts

The prototype resulting from the project is to be integrated in the parabolic trough power plant Andasol 3. However, the prototype is to be modular, which means that only a part, the power plant model, is specialised for the technology of a parabolic trough power plant. Thus, a product derived from the prototype can be used for all concentrating technologies, which use direct radiation as an energy source. For this purpose, only the power plant modelling must be adapted to other technologies.

Even the legal conditions which are analysed in this study, generally do not depend on the selected technology. That means that the same legal conditions can be used in nearly all cases, both for parabolic trough technology and in the other concentrating technologies.

4.4 UniSolar

Currently, massive expansion of solar thermal power plant capacity in the states of North Africa is being discussed intensively. An example of this is the DESERTEC concept co-developed by DLR. This power plant expansion aims to produce electricity at low cost in North Africa in solar thermal power plants, and to transport it to Europe and Germany in particular via high voltage direct current lines. In the medium term, it is planned to source 15% of European electricity requirements from these sources. In order to implement this massive expansion, political, technical, economic and socio-political priorities must be set at an early stage. The implementation of the DESERTEC concept thus also supports the heightened cooperation between the EU member states and countries of the Southern Mediterranean as part of the Union for the Mediterranean. UniSolar, funded by the German Federal Foreign Office, is based on this concept and can be viewed as a first step to practical implementation.

The objective of the project is the technological cooperation and targeted support of those countries in North Africa, which just started implementing the first solar thermal power plants. Technical optimisation options for commissioning and operation are to be used specifically and contribute to increasing the efficiency of the solar power plant section and the overall...
electricity generation. The local capacities are to be expanded via educational programmes, training courses, workshops and technology transfer, and a specific cooperation with the German industry is to be made possible. The distribution of the technology is to be guaranteed via correspondingly trained and supported local contacts and networking with one another. They can competently accompany and support project developments and technology developments in the target countries. These measures are intended to promote sustainable implementation of solar power plants and the development is to be speeded up via multiplier effects.

Target groups for the expansion of capacities and distribution of the technology on the North African side are research institutes, universities, industrial companies, experts, engineering firms, decision-makers and power supply companies in Egypt, Algeria, Tunisia and Morocco. Other states in Africa are to be added during the course of the project.

The Renewable Academy Berlin, with the support of Fraunhofer ISE, also offers workshops on solar thermal power plants around the world for decision-makers and engineers as part of the TREE project (Transfer Renewable Energy & Efficiency) funded by BMU.

5. Summary and outlook

A technologically leading role is the requirement for participating successfully in the rapidly growing market for solar thermal power plants.

The lack of a domestic market requires global operating companies and an internationally well-networked research and access to test facilities in the sun belt. Both is currently the case; however, rapidly increasing research budgets, in particular in the USA, China and the Gulf states, can lead to a shift in the market in the medium term. Therefore, public research and development budgets adjusted for the increasing turnover of the companies and their own research expenditure must be added to maintain a leading role in Germany.
Concentrating photovoltaics (CPV) for countries with high direct irradiation

1. Introduction

The ultimate objective of all research work in the area of photovoltaics (PV) is to reduce the costs for PV-generated energy and thus to provide a sustainable energy supply.

The current market is dominated by Si modules. Technologies on a thin-film basis (a-Si, CIGS, CdTe) reached industrial mass production in the last two years.

Concentrator photovoltaics are an alternative approach to reduce the costs per PV-generated kWh. The underlying idea is easy to understand: This technology reduces the need for comparatively expensive solar cell area, by focusing the sunlight via a low-cost optical concentrator. A small cell which converts the high irradiance efficiently is the target for the focused light. In order to concentrate the sunlight sufficiently, the system must track the sun’s path. Therefore, the concentrator systems are particularly suitable for countries with a high direct irradiation.

Concentrator systems are preferred as PV power plants in the kW-MW power range. The interest in this technology increased significantly in recent years, as the costs were reduced and system efficiencies of over 25% were reached in the field [1].

2. The technological basis of concentrator photovoltaics

Concentrator photovoltaics are characterised by the fact that the individual components such as cells, cooling, concentrator optics and tracking are highly interdependent and therefore must be optimised as a whole. Concentrator photovoltaics must therefore be viewed as an integrative technological approach. For example, the tracking precision requirements for the mechanics can be reduced if the optical concentrator is designed accordingly by using a second stage. This in turn can result in increased complexity during the assembly process. This example shows the concatenation of technologies and the complexity in the development of a concentrator system. Therefore, there is no one concentrator system – each system must be developed and analysed individually. As a result, there is a variety of possible system implementations.

The true evaluation of a concentrator system is not revealed until in the application, and is specified via the costs per generated kilowatt-hour (€/kWh). Of course, this evaluation value depends on the irradiation conditions, and thus on the location.

The variety of concentrator system approaches is easiest to explain by applying the concentration factor. The concentration factor of current systems ranges from 2 to 1000. Figure 1 shows two examples of system components: On the left, the low-concentrating ARCHIMEDES system developed at the ZSW in Stuttgart. It uses Si concentrator cells and has a single-axis tracking system. On the right, the high-concentrating FLATCON system developed at the Fraunhofer ISE in Freiburg, and prepared for market introduction by Concentrix Solar, Freiburg. This
The following section discusses the main components of a concentrator system briefly:

**The optical concentrator**

As optical concentrators, either lenses or mirrors are used. A second optical stage which is generally mounted directly on the solar cell is often used. Fresnel lenses are often used instead of heavy solid lenses. They require less material and can be produced more cost effectively. Where lenses are used, imaging errors, in particular chromatic aberrations, must be taken into account when designing the system. Mirror systems have advantages in such cases. The challenge for the mirrors is to produce highly-reflective coatings with long-term warranties cost-effectively. **Figure 2** is a schematic representation of various optical concentration concepts as currently used in systems.

**The concentrator cell**

The cells used in concentrator systems must deal with the high irradiance and the resulting high currents. Therefore, there is no one best concentrator solar cell. The solar cell technology must be adapted for the concentration factor. Resistance losses scale quadratically with the current densities, which requires a higher degree of metallisation of the solar cells, which in turn increases shading losses. Also, the solar cell is not lit homogenously, depending on the optical concentrator, which can be taken into account by designing the front contact grid.
 accordingly. Therefore, the “optimal” solar cell design is highly dependent on the system design. In general, it can be said that only slightly modified industrial silicon solar cells are used, in particular for low concentration ranges (Figure 1, left). Figure 3 shows an example of cell development at Fraunhofer ISE [2]. Here, the metal wrap trough (MWT) solar cell was modified such that it can be used for concentration factors of up to 20 depending on the design. Multiple solar cells, in which different III-V semiconductor materials are deposited above one another, allow extremely high efficiencies to be reached. This cell type is used in high-concentrating systems. Figure 4 shows the coating structure and characteristic curve of the Fraunhofer ISE record solar cell which reaches an efficiency of 41.1% at a concentration factor of 454 suns [3].

**Trackers**

Tracking systems have been utilised to an increasing extent for flat modules, as tracking can be expected to increase the yield by between 20-35% [4]. As a result of this development, there are now multiple providers of tracking systems on the market, which benefits concentrator photovoltaics. However, the precision and stability requirements for concentrator systems are significantly higher. The required precision depends on the concentration factor and on the optics used in the system. As a guideline value, a concentrating system with a factor of 500 aims for and reaches mechanical precision of 0.1 °.

A good control system is important to reach this goal. At Fraunhofer ISE in recent years, a development has been pursued, which integrates the tracker control into the inverter electronics:
The resulting tracker inverter reduces the costs of the concentrator system. For low-concentrating photovoltaics, a single-axis tracking system with a mechanical precision in the degree range is often sufficient. In general it can be stated that the reliability of the tracking system is not a problem and that the power consumption for the drive on average is significantly lower than 100 W [5], which is negligible with system sizes in the kW range.

3. Concentrator systems in operation

Concentrix Solar manufactures high-concentrating FLATCON concentrator modules. Since autumn 2008, a production line with a capacity of 25 MW has been available. This fully-automated production line is used to produce modules with efficiencies of 27%. The modules are mounted on two-axis tracking units. The nominal system capacity is 6 kW. Figure 5 shows a photo of a Concentrix concentrator system and a measured DC characteristic curve of the system. With favourable irradiation conditions, DC system efficiencies of over 26% have been reached.

Figure 5
Left: FLATCON concentrator system by Concentrix Solar. The aperture area is 28.8 m². On the right, the measured DC characteristic curve of the system is shown. An efficiency of 26% was measured.

Figure 6
Left: Photos of the 100 kW systems in Seville (top) and Puertollano (bottom) in Spain. On the right, the maximum AC power plant efficiency of the two systems from May to September 2009 is shown.
Figure 6 shows the maximum AC efficiency from May to September 2009 for two 100 kW power plants at the sites in Seville and Puertollano in Spain. The efficiencies remained constantly significantly above 20%, and peak values of up to 24% were reached.

4. Summary and conclusion

Concentrating photovoltaics have now reached a development level at which the transition from laboratory to industrial manufacturing has been made. This technology can now penetrate the market. The cost and yield analyses lead us to expect that CPV systems on sites with high direct irradiation can reach electricity generation costs which are significantly lower than those for classic PV technology. If these forecasts are proven true in the coming two years, this technology will grow rapidly.

Literature


Requirements for integration of wind energy into the grids of various countries

Introduction

In Europe and around the world, wind energy is developing at an incredible growth rate. Countries such as Denmark, Germany and Spain have created a major foundation for integrating wind energy with their pioneering work. In 2030, wind energy is to provide more than 25% of the electricity requirement in Europe [1].

This high percentage of wind energy generation presents an enormous challenge for reliable and safe integration of wind energy in supply grids. As a consequence, the need to manage wind farms like conventional power plants in terms of predictability and grid compatibility is increasing in order to guarantee a reliable and safe integration of wind energy in supply grids. The country-specific regulations and requirements for the energy market and electricity grids are framework conditions which must be taken into account when developing system technology and the tools for planning, monitoring and management.

The term “power plant properties for wind farms” indicates that wind energy generation must be controllable and reliable in accordance with the system requirements, and that wind turbines must support the electric grid in the event of disturbances. These capabilities are based on management of active and reactive power of the wind farms and their reactions in the event of grid disturbances such as fault ride through [2] capability, an ability with which wind turbines can survive temporary voltage drops and thus contribute to grid stability.

Grid integration status

One of the largest barriers to further development of wind energy technology is the restricted capacity of the transmission grids. Large-scale balancing of wind energy feeding by transporting energy long distances decreases major fluctuations to a great extent [3]. This requires an efficient and sustainable expansion and strengthening of the European transmission grid and, in particular, of the connection points, in conjunction with detailed planning and early detection of grid bottlenecks at a European level.

Future reliable and economic grid planning and safe grid operation also require reliable monitoring, better understanding and precise predictability of the respective grid status. This results in the need for improved monitoring, simulation and prediction tools, in conjunction with dynamic analysis and evaluation of the joint European system.

The development status of wind energy use in Europe is very different in the individual countries. For example, the installed capacity in Germany and Spain is at a double-figure gigawatt level, followed by Italy, France, Great Britain, Denmark and Portugal.

Worldwide, currently approx. 130,000 MW of wind capacity are installed, and the growth rate is immense. In some countries, wind power generation at times covers more than half of the entire load (Denmark, Spain). The challenges for an electric energy supply system with a very high proportion of wind energy are

- The variability of wind energy feeds,
- Forecast errors for wind feeds,
- The electric grid for absorbing and transporting wind energy.
The grid integration status quo in these countries is such that the grid can largely absorb and transport the energy from the turbines which exist today. However, the grids in some countries are rapidly approaching their capacity limits. When comparing the requirements for grid integration in various countries, it is not sufficient to use the installed wind capacity as a measurement variable. The impact of wind power feeding on grid operation also depends on the following factors:

- The percentage of wind power in the grid (% min, % avg, % max)
- The variability of the load
- The flexibility of the conventional power plant infrastructure
- Ways of increasing the flexibility of generation and load
- The structure of the grid (wind locations – load centres)

The degree of penetration can be measured by the energy or powerWind energy penetration in European countries.

In the IEA Wind Annex 25 [4], the penetration was also measured based on the minimum load and the grid capacity. This representation shows

<table>
<thead>
<tr>
<th>Region/case study</th>
<th>Load</th>
<th>Inter-connection</th>
<th>Wind capacity 2007</th>
<th>Maximum investigated</th>
<th>Maximum penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak MW</td>
<td>Min MW</td>
<td>TWh/a</td>
<td>MW</td>
<td>MW</td>
</tr>
</tbody>
</table>
| West Denmark real | 3700 | 1300 | 21 | 2830 | 2380 | 5,00 | 65% | 24% | 58%
| Denmark 2025 | 7200 | 2600 | 38 | 5190/6790 | 3125 | 6500 | 20,20 | 90% | 53% | 83%/69%
| Ireland 2020 | 8800 | 4560 | 49,2 | 1000 | 2150 | 5100 | 12,80 | 58% | 26% | 92%
| Portugal | 76000 | 24 | 427 | 2000 | 2389 | 38000 | 115,00 | 50% | 27% | 146%
| Germany 2015 | 77955 | 41000 | 552,3 | 10000 | 22247 | 36000 | 77,20 | 46% | 14% | 71%
| Spain 2011 | 53400 | 21500 | 246,2 | 2400 | 15145 | 17500 | 33% | 19% | 73%
| Sweden | 26000 | 13000 | 140 | 9730 | 788 | 8000 | 20,00 | 31% | 14% | 35%
the challenges at high wind feed rates in low load periods. It also illustrates the special features of stand-alone systems compared with well-connected areas.

*Table 2* shows the current and expected penetration of wind energy in some countries in Europe. For example, in Germany it is expected to reach 14% of peak load and 71% of the minimal load by 2015. With this high penetration rate, wind capacity will soon significantly exceed the load in many countries. The wind power generated must therefore be transported long distances to facilitate an exchange. One of the main tasks for research and the industry is to develop future grid planning tools for designing a sustainable, powerful European grid infrastructure. In particular, the new international offshore connections and an offshore super-grid must be designed.

**Future challenges**

Grouping multiple large-scale offshore wind farms and other distributed wind turbine groups to wind farm clusters [5] opens up new ways of optimally integrating yield-dependent generation into electric supply systems. The Wind farm Cluster Management System (WCMS) developed by Fraunhofer IWES is responsible for grouping the geographically distributed wind farms for optimal grid operation management and minimisation of the reserve and balancing capacity requirement, and mapping and managing it as a single large-scale power plant feeding into multiple extra-high voltage nodes. With the aid of new operating management concepts for active and reactive power control, higher levels of wind power can be integrated in supply systems.

As a result of the system topology, the following system levels must be considered:

- Individual wind turbine
- Individual wind farm
- Geographical, grid-topology and control-technical grouping of multiple wind farms to a wind farm cluster

For modern wind farms and with corresponding wind farm controllers, the following control and operation management strategies are currently state-of-the-art or achievable:

- Feeding reactive power based on setpoint specifications
- Maximum value restriction based on setpoint specifications
- Compliance with maximum gradients based on setpoint specifications
- Power restriction in the event of excess frequency

The following advanced strategies can also be implemented using the options above:
• Scheduled specifications (time-variable specification of maximum values)
• Voltage control in high/extra-high voltage grids
• Rapid voltage control in medium-voltage grids
• Provision of balancing capacity

Based on these options, future control and operation management strategies can be derived for wind farms:
• Reactive power feed
• Generation management
• Scheduled specifications
• Voltage control at high and extra-high voltage levels
• Provision of balancing capacity
• Primary control capacity

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[2] dena Netzstudie I


Off-grid power supply and global electrification

Introduction

The electrification of off-grid rural regions plays an essential role for a basic level of supply, in particular for economic development. Depending on the local framework conditions, different technical system concepts and business models are suitable for sustainable provision of a reliable and cost-effective supply of electricity. From small solar home systems, hybrid systems with photovoltaics, biomass, wind and hydro-power, to multi-megawatt stand-alone grids which can be integrated in integrated grid structures, FVEE member institutes, together with industrial companies, develop technical solutions, test systems and components and run trials in realistic conditions.

In addition to this, new financing and business models are proposed, which are intended to create incentives for investment, and support sustainable operation and possible expansion of the systems. Advantages result from the use of different renewable energy sources, which, thanks to the suitable system technology, are often competitive with standard diesel stations or conventional grid expansion.

Solar home systems (SHS)

A simple solar home system (SHS) for basic electrification consists of the following components: a solar generator, battery and charge controller, as well as the directly connected DC consumers. An optional inverter can also be used to supply AC consumers (Figure 1).

Such systems are used to supply energy-saving lamps, an increasing number of LED lamps, and some radios, televisions and refrigerators. The SHS charge controller connects the solar module (15..150 Wp) to the battery and the electricity consumers. It protects the battery against overcharging and deep discharge. As storage device, lead batteries with liquid electrolyte, bound in gel or fleece in a few systems, with a storage capacity of 3 to 5 days, are used almost...
All components must satisfy demanding requirements – in terms of efficiency, reliability and ease of operation. This is why Fraunhofer ISE develops and tests SHS components in the laboratory.

Worldwide, there are currently major programmes for widespread distribution of SHS, such as in Argentina, Bangladesh, Bolivia, China, India, Morocco or South Africa. The possibility of supplying remote households decentrally, simply and independently with electricity using SHS is considered a particular advantage of this technology. By contrast to central plants, these systems can be the property of the end users. However, even if the system is operated by a RESCO (Rural Energy Supply Company) and does not belong to the user, there is always a direct correlation for the user between their personal consumption and the status of the system. This reduces the coordination work compared with concepts featuring central supply.

In Ecuador for example, PV systems are subsidised by the state with the aid of a rural electrification fund (FERUM). Every year, new projects can apply for this funding. The PV systems for basic electrification consist of a 100 Wp solar generator and a 105 Ah battery for supplying DC consumers (three energy-saving lamps, one radio and a black and white television). In addition to this, PV systems with inverters in two sizes up to 200 Wp and over 200 Wp have been subsidised since 2007/2008. Now, systems with up to 800 Wp are installed at end customers’ locations.

Funding is US$3,200 or US$3,500 per household. The size and configuration of the individual systems are specified according to the requirements of the applicants or end users. As some areas are difficult to reach, the funding also takes transport costs into account.

Standardisation of components reduces costs. The local operator model, in which technical training by RESCOS and funding play an important role, is an important success of the PV project in Ecuador. End users must make monthly payments. As part of the DOSBE EU project [1a,b], Fraunhofer ISE was involved in the development of this operator model.

Hybrid systems

Supplying electric consumers in off-grid locations is challenging if it must be guaranteed continuously all year-round. Seasonal fluctuations of the energy from the sun, wind and water in particular mean that supply solutions which rely solely on one energy source require significant investments for electricity storage. Systems with different electricity sources are known as hybrid systems. Common combinations include PV-diesel or wind-diesel systems. Combinations of photovoltaic generators, wind turbines and diesel motors are also widespread.
Hybrid systems can be designed as DC systems, mixed DC/AC systems or pure AC systems. DC/AC systems are often used in farms or other small companies. When designing systems, planners must take into account that the inverter power must match the overall maximum consumer power. **Mixed DC/AC systems** are particularly suitable for combining medium AC loads with DC generators. At the same time, this also allows the battery on the DC side to be charged via a combustion generator (**Figure 2**).

Pure **AC hybrid systems** can be set up flexibly with modular components (**Figure 3**). Depending on the application and the available energy sources, renewable and conventional energy carriers can be incorporated. If the power converters and combustion generators are intended for the purpose, they can also be connected to the public grid.

The system is easy to expand via additional components or electricity generators to cope with increasing energy requirements. A mass-produced modular system for AC connected hybrid systems was built and tested for the first time in the European „Hybrix“ project [2] by BP-Solar, SMA and Fraunhofer IWES (**Figure 4**). It is now in use worldwide. This type of system can be used to supply all standard electric AC devices.

**Figure 3**
Hybrid system with AC connection
(Source: SMA)

**Figure 4**
Wind-photovoltaics-diesel-hybrid system in Spain
(Source: Fraunhofer IWES)
From an economic perspective, stand-alone systems with battery storage in the kilowatt power range are far less expensive than systems which use diesel generators only. Even larger hybrid systems which additionally use a diesel generator to avoid long-term battery storage can be operated at lower costs than stations in which diesel motors alone are used. The reasons for this are the high maintenance work required, the short service life and the very poor partial load efficiency of diesel generators.

In power supply systems away from the integrated grids, it is primarily the expandability and the type of connection of the individual components which play an important part. The AC connection with battery inverters which can be connected in parallel (Sunny IslandTM) can connect almost any kind of power generators and all standard consumers to the hybrid system. Figure 5 shows typical generators which can be combined easily using the SELFsynchronous control technology patented by Fraunhofer IWES. The system is easy to expand on the consumer side and on the generator side.

**Figure 5**
Modular system for AC connected hybrid systems
(Source: SMA)

**Stand-alone grids and microgrids**

Stand-alone grids can be used for several remote houses or loads outside the integrated grid. Grid interconnection levels the load profile and increases the supply security. Stand-alone grids can be fed from a central power plant, a hybrid system or multiple decentralised electricity sources. In the integrated grid, the number of consumer-related independent generation systems, e.g. photovoltaic systems and combined heat and power plants, has increased significantly in recent decades. This technology can also be used for stand-alone grids. However, high decentralised power inputs may not endanger the stability of the grid.

Feed-in tariffs could be used to create incentives for investments and for sustainable operation of the remote generators in the stand-alone grid. In this way, grid participants with more financial clout could help to finance the overall system and would thus also ensure that it runs smoothly.

In principle, a collectively supported feed-in tariff could be used for such systems, similar to the German Renewable Energy Sources Act (EEG). The WG 4 – Rural Electrification working group of the European PV technology platform developed a proposal for this [3]. The technical feasibility of such stand-alone systems was demonstrated on the Greek island of Kythnos (Figure 6). This is similar to independent generation in the integrated grid, but research is still required for organisational implementation.
Stand-alone grids can be connected to one another or to the integrated grid using suitable, i.e. grid compatible control technology. This allows so-called micro-grids to be formed temporarily, which can then continue to operate without problems even if the main grid fails (Figure 7).

It was proven [5] that a variation of the grid frequency – imperceptible to the user – is suitable to derate excess solar power fairly (Figure 8).

A continuous decentralised derating of PV systems becomes necessary when the batteries are fully charged and electricity is in relatively low demand. It is crucial that the PV systems installed in houses are derated in a fair manner. This is achieved automatically by increasing the grid frequency. Figure 9 demonstrates this for houses on the island of Kythnos.
Financing and business models

The best-known financing model for SHS worldwide is via micro-loans, which also enables poor rural population strata to purchase small systems. Financial scope for paying down the loan is provided by the dropped costs for kerosene. In its basic form, this business model works without government subsidies. It is widely recognised as being highly successful and is increasingly supported by development institutions.

The Grameen Shakti Bank in Bangladesh is an internationally recognised pioneer. It offers the customer not only financing but also guarantees professional installation and maintenance by certified and specially trained contractors. To date, Grameen Shakti has financed more than 200,000 systems.

Common business models for solar home systems also include leases (e.g. SolarLuz), the “Fee for Service Model” (e.g. the Moroccan PERG-Programme, based on a Public Private Partnership) and subsidies for the acquisition costs [6].

Given the very low income levels, mini-grids in rural areas of developing countries are generally not economically self-supporting. A common form of financing that allows independent electricity generators to make profit is a subsidy on the investment combined with tariffs covering operating costs for end customers [7].

This model, for example, is often used by African “Rural Electrification Agencies”. In practice, however, it has often been shown that the users’ low capacity or willingness to pay causes the cash flow of these projects to remain below expectations.

The moment the batteries need replacing is therefore generally regarded as critical to the sustainability of this financing model.

Following the feed-in tariff, the Joint Research Centre of the European Commission (JRC) developed a tariff concept tailored to mini-grids in cooperation with the EU PV technology platform named Regulated Purchase Tariff (RPT), which is a strong incentive for independent electricity producers to continuously operate the system while giving financial leeway for required repairs and replacements of system.
components. Depending on the actual electricity generation, compensation guaranteed by the government will be granted, which will ensure the sustained operation of the system in combination with the user fees. This model has yet to be tested in practice. The RPT corresponds to the development policies of output based aid, which is becoming increasingly important.

Summary

In order to electrify off-grid regions, systems in the range of under 50 watts to systems of several megawatts were developed that are fed with renewable energy.

Very small systems which are privately owned by the electricity consumers are already operated sustainably worldwide. There are also appropriate financing and operator models.

An even greater challenge are the so-called mini-grids that can be successfully operated as stand-alone grids but which impose significantly higher requirements to the organisational framework. The advantage of grid interconnection is both the equalisation of generation and load and the higher energy yield as less power has to be stored or derated. The goal is to build power supply grids for densely populated areas which offer a secure supply and a high grid quality and can possibly later operate in an integrated grid. The challenge now is to develop financing and support models and to provide incentives for investors and the sustainable operation of the power supply systems that can be used in the respective regional socio-cultural environments. The “Renewable Energy Regulated Purchase Tariff” [3] is a viable model especially for stand-alone grids which, however, still needs to be tested in practice.

The development of grid-compatible stand-alone systems, which has been promoted in Germany since the nineties, has also allowed for a technological edge for the next generation in grid technology of integrated grids. The systematic introduction of modern information and communication technology at the distribution grid level, promoted under the slogan “Smart Grids”, also benefits from this preliminary work. An example is the so-called micro-grid that can work as a distribution grid in an integrated grid and, in the case of a blackout, can ensure supply as a stand-alone system.

Acknowledgement

The research upon which this article is based would not have been possible without the support of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the European Commission.
Literaturliste


