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Innovative Development of Renewable Energies

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Federal Ministry for Food, Agriculture and Consumer Protection (BMELV)

Contents

Summary

In this background paper from the Renews Special series, the progress achieved in renewable energies is described for each segment of the renewables industry. However, the overview is limited to those types of energy which have managed to occupy a major market segment since the introduction of the Renewable Energy Sources Act (EEG) and the Market Incentive Programme (MAP) for renewable heat. Deep geothermal energy has been purposely left out of the overview, since it is used only in single projects and hence cannot show solid progress on a broad basis as yet. Hydroelectric power too has not been addressed, since it has attained technical maturity over its 100 years of history, and therefore has relatively little room for improvement today.

At the beginning of 1991, the funding of research for renewable energies was for the first time complemented by an effective instrument for market entry: henceforth, the Electricity Feed-In Law (StrEG) obliged regional monopolies in the then not yet decontrolled electricity market to take the kilowatt hours generated by hydroelectric, wind, solar and biogas systems into the grid and to compensate them according to pre-defined tariffs .

In April 2000, the StrEG was then replaced by the even more effective Renewable Energy Sources Act (EEG), which had the goal of making economically viable operation possible for all types of renewable energy facilities of electricity generation, by ensuring cost-covering tariffs. In accordance with the great variety of energy sources, the tariffs were also graded individually, so as on the one hand to make profitable operations of the production facilities possible, and on the other to avoid over-subsidizing them. The successes of the EEG are discussed in another background paper in the Renews Special series, no. 41, which is accessible in English on the Internet under: www.renewables-in-germany.com.

Although neither the StrEG nor the EEG explicitly provided for any research funding, they have nonetheless generated considerable innovations in the respective industries. Thanks to the long- term guarantee of tariffs these technologies have been brought out of their niche markets, and mass markets have been created in each segment of the industry. These long-term prospects made the establishment of in-house research and development departments possible for companies. Especially the annual reductions in the level of feed-in tariffs stipulated under the EEG and the competition within the industry encouraged manufacturers to improve their own products by means of development – which, in retrospect, they did in an impressive manner. Thus did technological developments move ahead which would have hardly been possible by means of research subsidies alone.

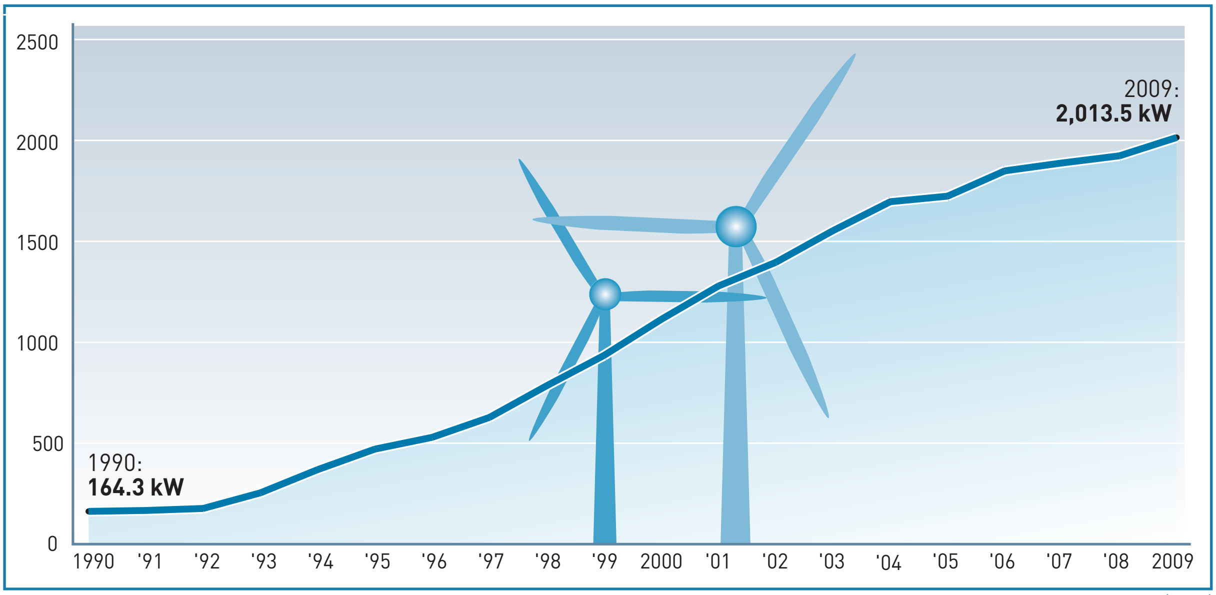
This has been shown very clearly in the case of wind power: After the failure of the large 3 MW Growian wind power system due to technical problems during the 1980s, the StrEG, and later the EEG, initiated a harmonious development which brought even larger machines to the stage of series production. Today, systems of the Growian class have long since become an established technology.

Wind Power

The most visible progress of wind power is the steady increase in system size. Starting with systems of the 100 kW class around 1990, the technology developed steadily. By the mid-nineties, newly installed turbines in Germany had capacities in the 500 kW range. By 2000, this had already risen to more than 1,100 kW, and in 2009 the average capacity of new systems for the first time even passed the 2 MW mark. Today, a series of systems with 5 MW of capacity have been established.

Increase of wind energy system capacity by a factor of 12 since 1990

Average capacity of newly installed wind power systems in Germany, in kilowatt



Source: Deutsches Windenergie-Institut (DEWI)

Rotors have not only grown larger and towers are higher now; profits too have increased due to improved technology, as the example to the company Enercon shows:

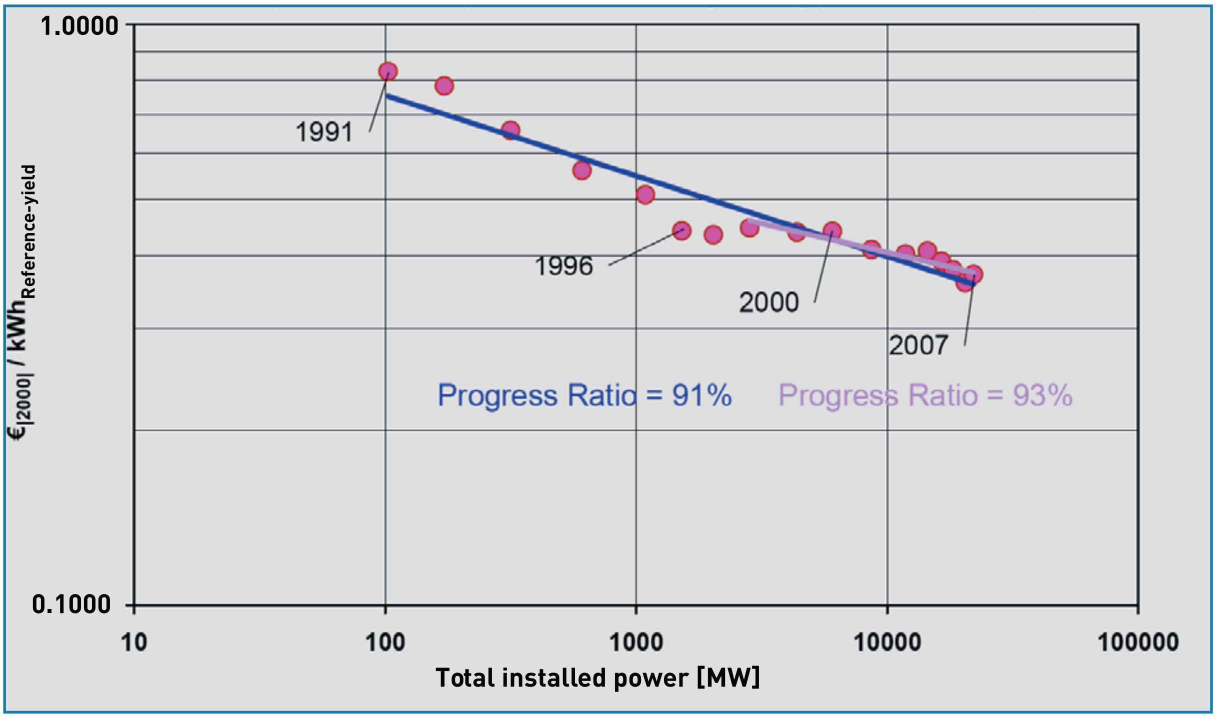
System type	Rotor diameter in m	Installed power in kW	Hub height in m	Annual energy yield* per rotor disk area in kWh/yr./sq m*
Enercon E-66	66.0	1,500	67	886
Enercon E-66/18.70-2	70.4	1,800	65	907
Enercon E-66/18.70-3	70.4	1,800	65	948
Enercon E-70 E4	71.0	2,000	64	1,069
Enercon E-70 E4	71.0	2,300	64	1,101
*Annual energy yield based on the EEG reference yield				

Source: www.wind-fgw.de

At the same time, the price per kilowatt hour has dropped by more than half since 1990:

Wind energy learning curve, the WEA price per kWh of annual energy yield

(reference site)



Source: Fraunhofer ISET Wind Energy Report Germany 2008

The higher profits and lower prices are due to a variety of improvements which have only been made possible by many thousandfold use of the systems in practice. One major factor has been the height of the systems. Today's hub heights of up to 160 metres ensure that the rotors move into layers of air with stabler wind conditions. Not only does wind velocity increase with altitude, but turbulence is also reduced. Moreover, the development of special low-wind systems characterized by large rotor disk areas relative to the generators have ensured increased yields at mediocre inland sites.

The design of the systems too has improved considerably in recent years. Today, new wing profiles increase yields and lower flow noise – two factors which clearly go hand-in-hand as air noise is always the result of loss-inducing turbulence. Enercon for example has angled the tips of the rotor blades, which makes them less vulnerable to turbulence. A more balanced surge flow is thus provided along the entire length of the blade profile, leading to yield increases of up to a factor of twelve.[1] This additional yield is also reflected in the cp values of the systems, which is improving continually. The output coefficient cp is the ratio between the primary energy (the wind blowing through the rotor surface) and the final electricity produced; it thus indicates the efficiency of a wind power system. The theoretically possible maximum value is 0.59. Modern systems today achieve values of approx. 0.5; three years ago, most systems on the market were still in the range of 0.43 to 0.47.[2,3]

At the same time, today's machines are designed with variable rotation speeds. The connection to the power supply system is thus carried out via a frequency converter, which means that the systems no longer need fixed rotation speeds set to the grid frequency. Thus, the wind turbines can even operate at low wind speeds, and also make better use of gusts by means of short-term acceleration.

1) Source: Enercon: http://www.wind-energie.de/fileadmin/dokumente/veranstaltungen/Windenergie_in_Deutschland/Entwicklung%20der%20Windenergietechnik.pdf
2) Source: http://www.handelsblatt.com/technologie/forschung/groesser-geht-nicht-effizienter-schon1351780
3) Source: http://www.wind-energie.de/de/technik/physik-der-windenergie/leistungsbeiwert/

Most of these optimized processes have only become possible because the system manufacturers today – unlike in the early days – make the key components of their systems themselves. They are therefore better fitted to one another, which improves yields and lifespans.

Data communication too can improve electricity yield. Remote monitoring reduces downtimes and increases yields. Sound diagnosis is today established as an instrument of operation supervision in the systems. Also, protection of the systems against lightning has improved as the result of such measures as integrated lightning rods in the blades.

New generator concepts improve efficiency

One important element of the improvement process is based on generator development. An example is the ring generator: it needs no transmission unit, because the rotor of the wind mill is coupled directly to the rotor of the generator. That makes the machinery not only more efficient, but also quieter and less prone to wear.

Another advancement, the use of permanently excited generators, can achieve a degree of effectiveness of 98% at full load, slightly more than the 97% of traditional synchronous machines. Moreover, generators with permanent magnets can be designed with 30 to 40% less weight than comparable conventional designs, with dimensions reduced by a quarter.[4]

The greatest advantage of permanent magnet technology over the traditional generator can be seen at partial loads. The prerequisites for manufacturing such high performance magnets were new materials based on such rare earths as neodymium; these could be produced only within the last 15 years. Only then could permanent magnets be made with not only a sufficiently high energy density, but also enough stability against demagnetization.

Other new developments

Wind power systems also increasingly provide services for the power grid, for instance contributing to the maintenance of voltage and frequency levels in case of grid defects. This is now stipulated in the System Service Ordinance. The incentive for this was often a bonus provided under the EEG, which made it attractive for operators to upgrade their systems. This in turn motivated manufacturers to achieve the necessary technical innovations.

In addition, the integration of wind power into the grid was made easier by improved wind forecasting. The average error of previous-day forecasts is now only approx. 4%. This so-called root mean square error (RMSE) is calculated from the square root of the mean error.[5]

Need for further research and development

More experience is necessary, especially with regard to corrosion in offshore systems and possible damage due to sand at desert sites. Moreover, there is a need for the development of small wind power systems, which have not been promoted under the EEG to date, and are therefore hardly present on the market.

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4) Source: http://www.handelsblatt.com/technologie/forschung/groesser-geht-nicht-effizienter-schon1351780
5) Source: Information from Energy & Meteo Systems, Oldenburg

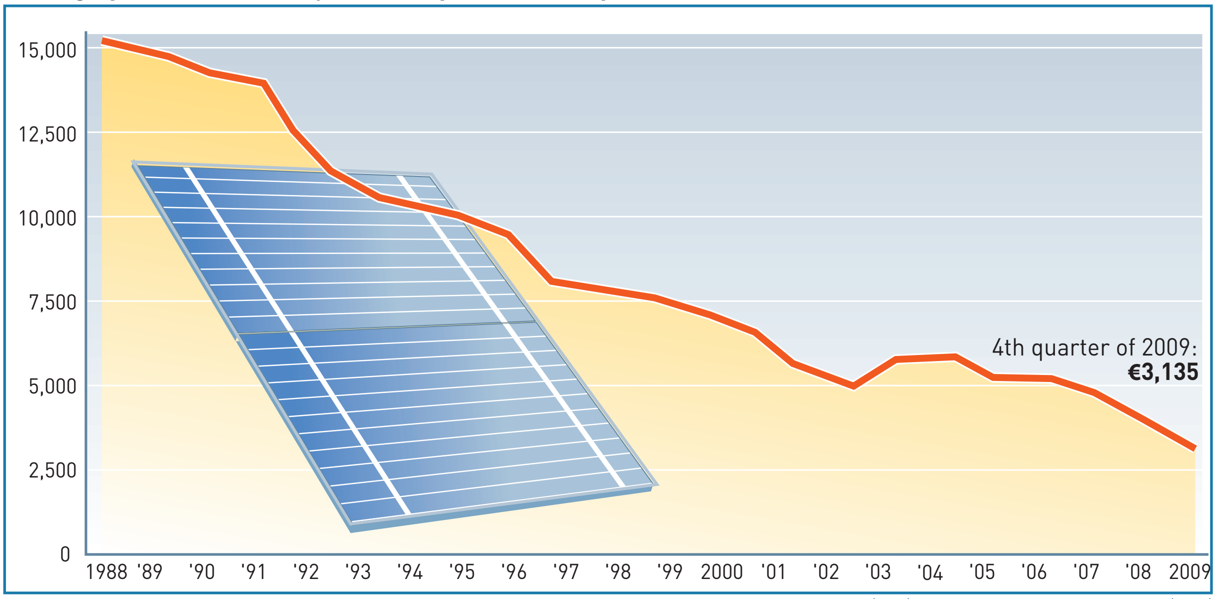
Photovoltaics

One of the decisive advancements in photovoltaics is the continuous price drop, which has generally matched the learning curve of economic theory.

Thus, every doubling of the quantity produced worldwide has brought with it a price drop of 15 to 20%. In 1990, one kilowatt cost approx. €14,000 (system costs); by 2000, the price was only €7000, and for the last quarter of 2009, the industry forecast was €3135.

The development of costs for photovoltaics

Average prices in Germany in euros per kilowatt (peak)



Sources: Deutsche Gesellschaft für Sonnenenergie (DGS), German Solar Industry Association (BSW)

The price drops have been achieved through a variety of factors

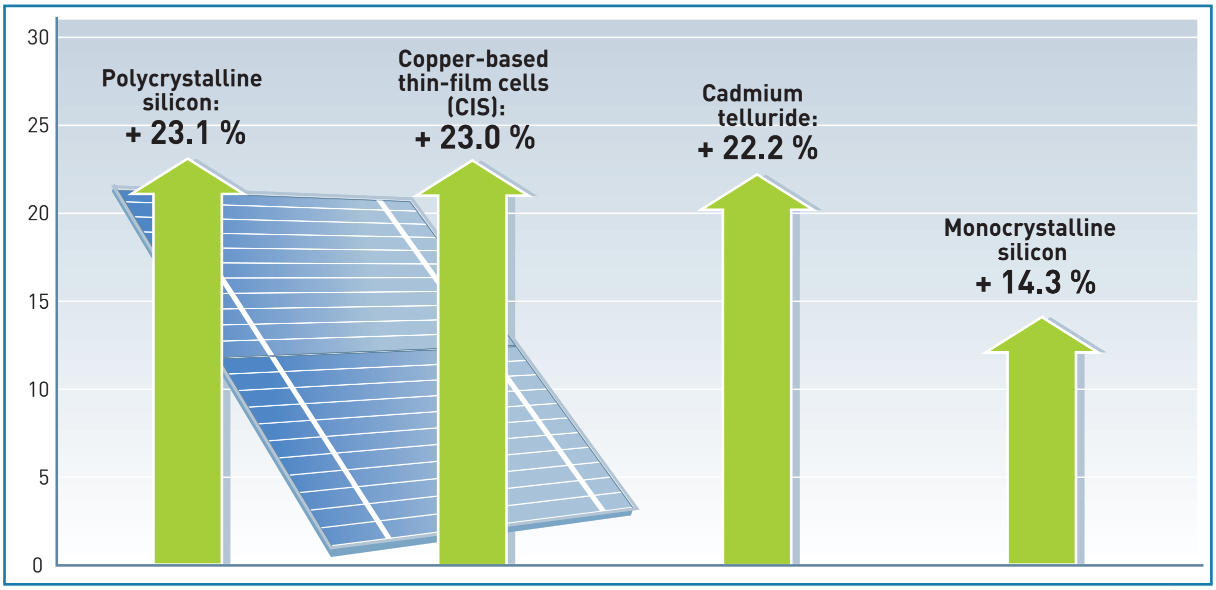
One important aspect is materials savings: Today, wafers of about 200 µm of thickness are normally used for crystalline silicon cells; five years ago, 300 µm were still normal in the industry. Further enormous savings of material are technically possible; researchers have already experimented with 40 µm wafers; to date, however, they have had to produce them by grinding down thicker wafers, which is neither economically nor technically a practicable solution for mass production. If thinner wafers can be manufactured and processed industrially without problems, even thicknesses of less than 100 µm are possible.

Another key factor in the price drop has been the development of larger production lines. Today, systems for the production of silicon cells are delivered ready to operate by the manufacturers; no longer are they specially ordered. This permits considerable economies of scale.

Another price benefit has been that the degrees of effectiveness of modules have been boosted by better cells, which have reduced the required surface area per kilowatt, and hence the costs – for many cost components are surface-area-related. At the beginning of the 1980s, the modules still had a degree of effectiveness of only about 8%. In 2003, the classic silicon modules reached a power yield of 13%, while today, the average modules on the market achieve 16%, and top of the line products almost 20%. Key factors for these improvements include better dosing, coating and bonding procedures.

Development of the degrees of efficiency of solar cells

Percentage increase in the degree of module efficiency in series production, 2003 through 2010 (indexed to 2003 as 100%)



Source: Deutsche Gesellschaft für Sonnenenergie (DGS)

The energy consumption in the production process too is continually falling. The energy amortization period of a solar system, using crystalline silicon modules, including all system components, such as the inverter, is today approx. 3.5 years, given German sunlight conditions. For systems using thin film modules, it is far less than that.[6]

Other improvements achieved

The lifespan of modules has also improved: during the early 1990s, there were still modules on the market which showed considerable capacity loss, and even catastrophic failure, after only a few years. The main problem was penetrating dampness. But much has been learned in the industry since then. Today, quality is ensured by tough tests to which the manufacturers subject their products – tests using accelerated ageing. In the "damp heat test" for example, modules are exposed to conditions of 85°C and 85% atmospheric humidity for a period of 1000 hours (approx. six weeks). Another test is the stress test, which uses temperature fluctuations between 85°C and -40°C. These methods of testing have already been established in a DIN standard. Field tests have also shown that in practice, systems installed after the turn of the millennium generally have higher annual yields per installed kilowatt than photovoltaic systems from the early days.

Yield increases and cost reductions in photovoltaics depend not on modules alone, but also on the PV inverters

The PV inverters too have experienced a considerable price drop: between 1990 and 2004, the price of the devices per watt has been halved, which means a 5% price drop per year. Today's specific price, measured against the 1990 level, has even dropped by more than 75%. At the same time, the degree of effectiveness has increased[7]: the yield of grid-connected PV inverters has risen from about 90% in 1990 to a peak of almost 99% today.

6) Source: Fördergesellschaft Erneuerbare Energien e.V. (FEE)
7) Source: Information from the SMA company

Lifespans too have improved steadily – in the early days, failures of inverters were the most frequent source of defects. Today, inverters are designed to last at least two decades. The so-called MTBF value – for "mean time between failures" – is 100,000 hours.

Photovoltaic systems also render grid services

Moreover, photovoltaic systems today are no longer merely in-feeders, delivering their power to the grid with no concern for the situation there; they also increasingly serve as voltage stabilizers. According to the amended Medium-Voltage Guideline, facilities which feed solar power into the medium-voltage grid must "be able to contribute to voltage stability during grid feed-in". The goal of this so-called "static voltage stability" is to keep "the slow changes in voltage in the distribution grid within reasonable limits" in normal operation.

Photovoltaics facilities can also help prevent grid collapses: the key word here is "dynamic grid support", which means that the facilities can work to prevent grid collapse in case of voltage drops in the high and maximum voltage grids. In the past, voltage drops could trigger a domino effect of failures of solar systems, which then aggravated the voltage drop.

Finally, the facilities can also deliver reactive power: the next step is a re-drafting of the Low Voltage Guideline as well. It can be assumed that all new solar facilities which feed into the low voltage grid will contribute to voltage stability. They will, if needed, also have to provide capacitive or inductive reactive electricity.

Further need for research and development

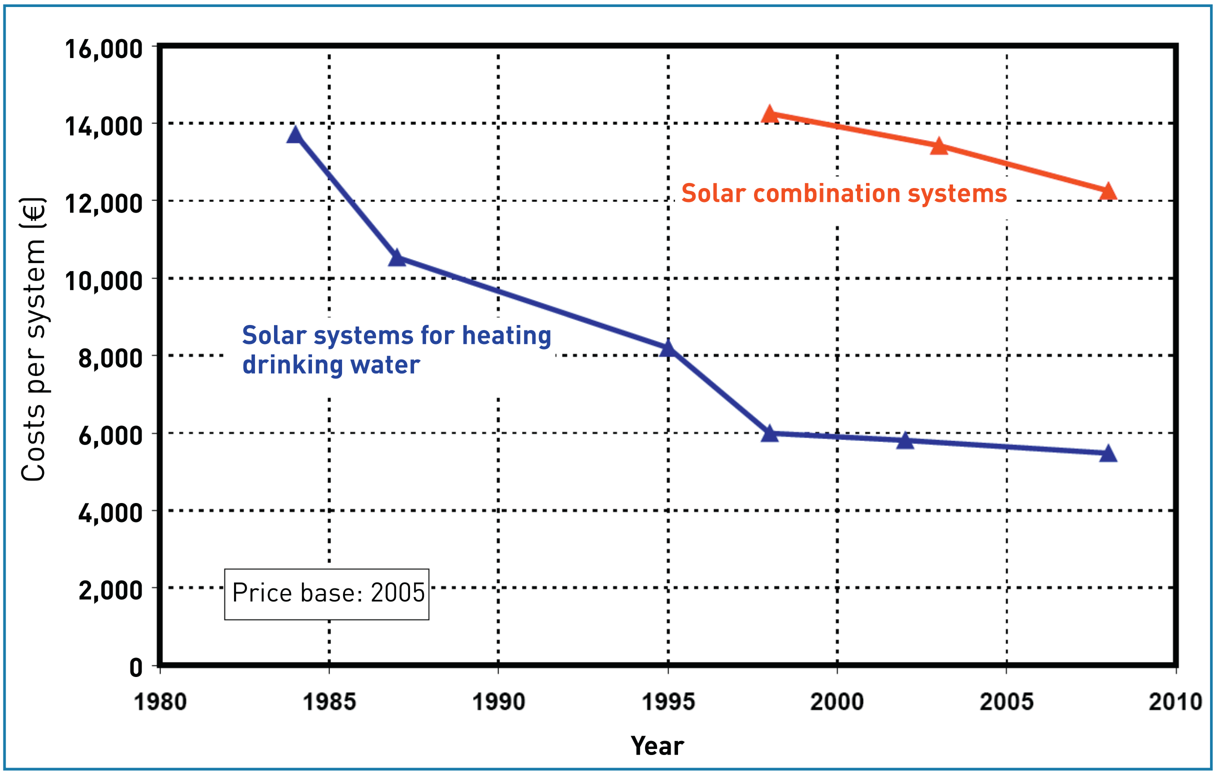
Further efforts are needed both to increase the degrees of effectiveness of new procedures and new semiconductors, and to reduce manufacturing costs. The expanding tasks needed to support the grid will make adjustments of the inverter hardware and software necessary.

Solar Thermal Energy

Solar collectors and the accompanying system components have become ever more favourably priced in recent decades and years. Measured by heat output, the nominal price of a solar thermal system is today 45% of what it was twenty years ago. There are several reasons for this cost reduction: the copper sheets are now thinner, and alternative metals such as aluminium are being used instead of copper. Also, new welding technologies, often with lasers, are being applied today.[8]

Development of the average costs for thermal solar systems in Germany

incl. VAT and installation



Source: Publication of the Warentest Foundation

At the same time, the yields of flat collectors have improved. Experts in the industry estimate a rise in yield of approx. 0.5% per year.[9] This is due to better insulation and double glazing, as well as to improved glass – soda-lime glass has replaced borosilicate. Moreover, the selective coatings of the absorber sheets, which need to attain as high as possible a rate of absorption, have been improved. The anti-reflex layers on the glass plates have also an important function. They are basically manufactured from a well-known material for optical glass, but their use for solar thermal energy involves additional requirements: The coatings must be manufactured on a large surface at an industrial scale, they must be reasonably priced, and they must withstand environmental conditions for decades. Also, the yield of tube collectors has been increased by placing weak concentrators behind them. And last but not least, the prices of the collector systems have been reduced steadily.

8) Information from the Fördergesellschaft Erneuerbare Energien e.V. (FEE).
9) Information from the Research and Testing Centre for Thermal Solar Systems (TZS), University of Stuttgart

Further need for research and development

Dealing with stagnation is still a challenge: on sunny days, when no heat is used, the collectors can be damaged by overheating. This can cause problems, especially for large systems. One possibility is switchable glazing, the transparency of which can be reduced in case of danger of overheating.

Another area of current research is the increased use of synthetics in collectors. They are first of all attractive in terms of price. Also, possible bottlenecks can be avoided if the rapidly increasing demand for solar collectors leads to a shortage in metallic resources. The challenge is finding substances which can withstand both high temperatures and high pressure. In theory, absorber layers are being considered which change their absorption behaviour when certain temperatures are exceeded, and reemit more of the incoming energy.

Like the collectors, the heat storage units too deserve attention. In addition to water tanks, which are becoming ever more efficient due to such innovations as vacuum insulation, phase change materials (latent heat accumulators) and especially thermo-chemical storage facilities are now available. In the latter technology, two substances are separated during the filling process to produce an endothermic reaction, and are recombined in an exothermic reaction when heat is needed; they bear especially great promise for the future.

Finally, it is of fundamental importance to bring large systems for the use of process heat out of their niche. One prerequisite for this is the standardization of the technology.

Biogas

Methane yields have increased by improved incorporation of the substrate, and by process monitoring. Moreover, new processes have made an optimum adjustment of fermentation to the respective substrate possible. One example is so-called dry fermentation.

At the same time, block-scale thermal power plant technology has been developed further, leading to higher degrees of effectiveness: Otto gas engines, which in 1994 still had a full load effectiveness level of approx. 34%, today reach the 42% level. Degrees of effectiveness at partial loads have also increased at the same rate. This progress is primarily due to the rise of compression ratios and the shortening of burn times. Moreover, the valve control in the Miller process has been optimized. In addition, the shut-off times of the valves are set variably, which provides a new range of possibilities for performance and effectiveness optimization.[10] The emissions of harmful substances have also been reduced, on the one hand through the lean-burning engine concept and on the other through improved exhaust fumes treatment. Here, advanced sensor systems are an important factor.

Like the Otto gas engines, dual-fuel engines too achieve a considerably higher yield today than ten years ago. In 2000, the degrees of effectiveness here were between 36 and 38%; now, a level of 47% is possible, and 50% is already the target. At the same time, the use of ignition oil in the engines could be reduced: ten years ago, a share of 8 to 10% was widespread for co-firing. Today, the systems in series get by with 2 to 3% shares of ignition oil, and on the test bed, they even do with just 0.5%.

Great progress has also been achieved in the processing of biogas to biomethane. The first system was built in 2006; by the end of 2009, some 30 biogas systems were already connected to the nationwide gas grid.

10) Presentation: Jenbacher (GE) "Modern Engine Technology", Apr. 2010.

Further need for research and development

The fermentation process must be developed further. To date, biomass is mostly fermented in a tub, but in future, the process is to be carried out in two to three stages, in different fermenters. There is also still a need to optimize the processes for biowaste utilization; substrate processing is often not carried out in the best possible manner.[11]

Solid Biomass (wood-fired power plants and wood-pellet heating)

The greatest progress in power plant technology has been achieved with large biomass power plants. Supported by the innovation bonus provided under the EEG, so-called Organic Rankine Cycle (ORC) systems have been developed further. The ORC process is a very efficient alternative to the steam turbine. It is primarily useful for relatively low burning temperatures, which prevail in small wood-fired power plants.

Among the small systems, primarily pellet heating has been developed further, and here, it is primarily the operation which has been improved; this has considerably reduced the vulnerability of boilers to disturbance. Mechanical cleaning mechanisms are the key here, for instance at the firebox and the heat exchangers. These can remove slag build-up which can lead to malfunctions. At the same time, emissions have been reduced by more precise burning control and burning monitoring.

The optimization of the flue gas direction via the combustion chamber also ensures better burnout of the exhaust fumes (the so-called primary emissions reduction). There has also been progress in secondary emissions reduction (the filter system). And finally, it has become possible to modulate the output, which has enlarged the field of application of pellet heating considerably.

Further need for research and development

Emissions values must be improved further in future.

Conclusions

Under the EEG and the MAP, renewable energies have not only experienced quantitatively rapid development, but have also progressed from a technological point of view; this could hardly be foreseen just ten years ago. By a continuation of market incentives in the form of long-term guaranteed feed-in tariffs for electricity and investment aids in the heating sector, this development can be carried forward during the coming years. In that way, new technological openings and lower expenditures for systems will also be achieved in future.

11) Information from the Schnell company, Amtzell.

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