3. The importance of research and development

The technological, economic and sociological challenges relating to the transformation towards the Energy System 2050 can only be overcome with research and development.

Moving from the current energy system to a sustainable, emissions-free or emissions-neutral system requires constant advances in renewable and energy efficient technologies, and supplementary social research.

This is because the renewable energy technologies which are available today are not all yet sufficiently developed to meet the challenges of a mass market. New materials to replace expensive or scarce elements, process engineering, systems engineering, communications technology etc. must be developed for the the high level of materials conversion. Technological and infrastructure errors should be avoided and supply security should also be safeguarded during the transformation (no regret strategy).

The transformation phase thus requires both the development of transitional technologies and continued monitoring through system-analytical research and technological assessment.

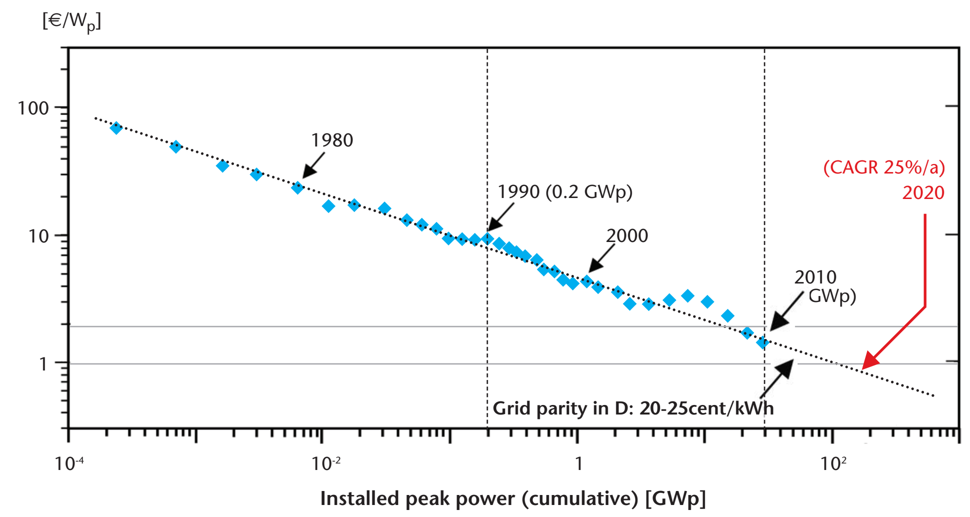
Cost reduction through the learning curve effect

A significant advantage for renewable energy is the fact that, the more it is used, the more its costs decrease.

Figures 20 and *21* show the advances in reducing costs with the example of wafer-based silicon photovoltaic modules and PV inverters. Over a long period, the learning curve shows a reduction of 22% in the cost of modules and inverters when the cumulative number of installations is doubled. This reduction in costs is the result of research and development, together with technological advances such as an increase in efficiency and reduced spending

Figure 20
Price-learning curve of c-Si PV modules (As of September 2009)

Source: G. Willeke, Fraunhofer ISE [37]



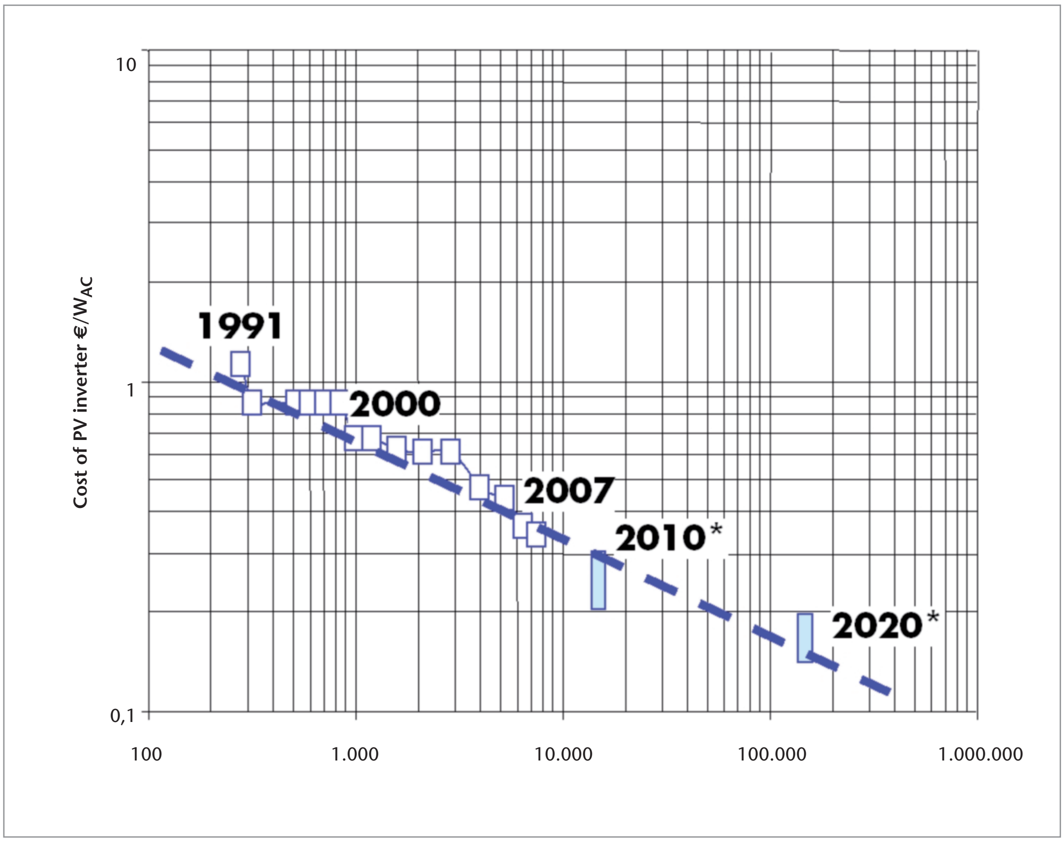


Figure 21
Learning curve for photovoltaic inverter

Source: M. Meinhardt, B. Burger, A. Engler: "PV system technology – Engine for cost reduction for photovoltaic power generation"

on materials, improved production technology, more efficient marketing and other economies of scale. Costs are therefore reduced when research and development takes place in institutes and in industry, in combination with continued market expansion.

Research and development is therefore an important requirement for future cost reductions. The dynamic of technological development also rises significantly with growing market volume, which is why research and development activities must be increased accordingly.

Further learning curves for different renewable energies are put together in *Figure 22*, in which the costs are considered in relation to energy produced. It thus becomes clear that all renewable energies are competitive with conventional fossil energy sources if their overall share is about 10% or more. This applies to all in the same way, cost effectiveness is therefore not a fundamental question, but only a question of time:

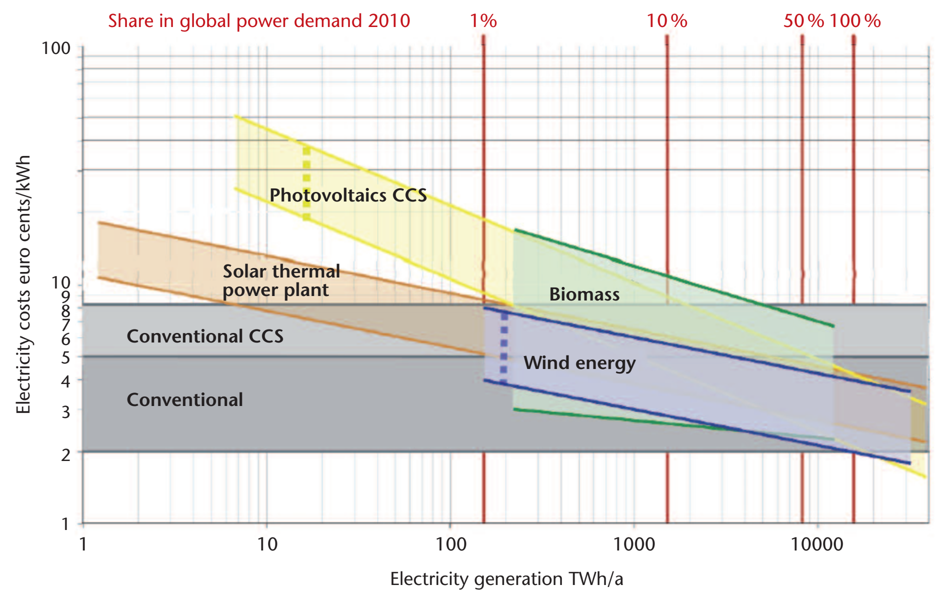
- Photovoltaics currently has a global share of slightly more than one-tenth of one per cent, but its learning curve shows a decrease in costs of 20% if the installed capacity is doubled.
- The global share of wind energy is already about 1.5%. In the last few years annual growth rates for wind energy have been between 30 and 40%. In fact this will turn out to be slightly lower in the next few years, but here as well, the learning curve shows a fall in costs of 10% if installed capacity is doubled.

Triggered by the Renewable Energy Act, research and development has received a significant stimulus from the economy. *Figure 23* shows the costs of electricity and the EEG fee payments for Germany. In the near future, photovoltaics will, with the planned reductions, achieve so-called so grid parity with domestic electricity. From 2020 the electricity costs of fossil power plants will be significantly higher than those of wind and PV. This is also reflected in the differential costs of power generation, in which a transitional period is assumed, between 2020 and 2030.

Figure 22

Potential trends in the cost of electricity from renewable energy – worldwide

Source: J. Schmid, Fraunhofer IWES 2010

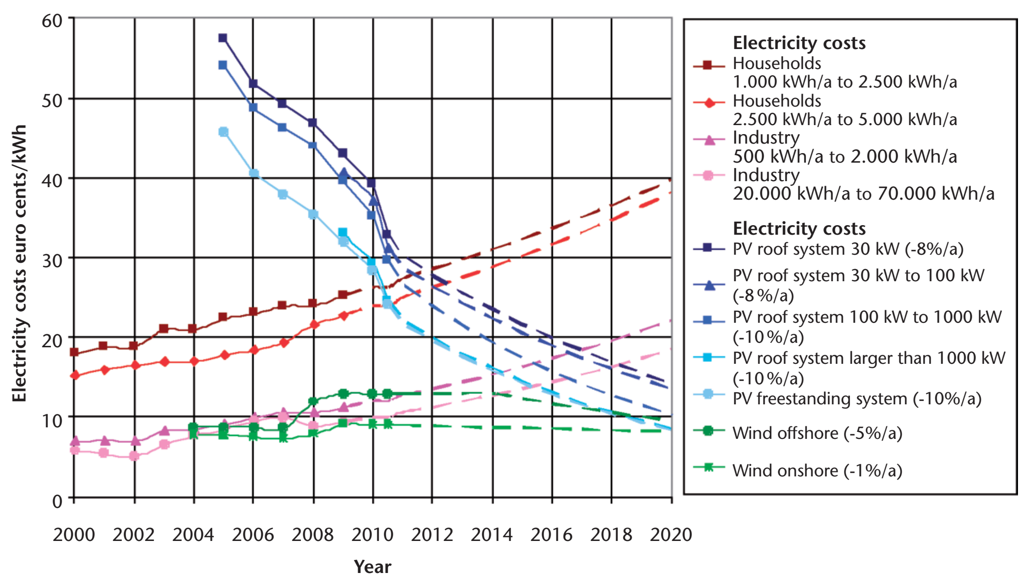


The starting values of the cost bands show currentglobal amounts and costs, the final values correspond to the potential of the pathway shown as an example. Trends in power generation costs in accordance with the learning rates for each technology as a function of global annual power production in double logarithmic application in comparison with (actual) constantly underpriced electricity costs for conventional power plants today and in the future, using CO_2 carbon capture and storage (CCS).

Figure 23

Trends in electricity costs and EEG fee payments in Germany

Source: BMU and BMWi



3.1 Research and development from the viewpoint of the Energy Concept and long-term research goals to 2050

To translate the Energy Concept that is being proposed, extensive research work will also be needed in the future in the field of efficiency increases, supply technologies for renewable energy, systematic improvements and acceptance by users. The most important research fields from the viewpoint of the Energy Concept 2050 are outlined as follows.

3.1.1 Energy efficient and solar construction

A particularly important aim of research and development is firstly to significantly reduce energy demand in the building sector and to supply residual energy demand using renewable energy sources. The building sector can make a substantial contribution to sustainable energy supply through energy plus houses in the new build sector, and the gradual harmonisation of the building stock to the low energy standard. The speed of this harmonisation largely depends on funding for research and development, which is determined by politicians.
Key elements are:

Long-term research and development goals

- Passive houses, energy plus houses and solar active houses become the building standard, depending on the region and demand
- novel, cost-effective heat insulation systems with additional functions, such as ventilation ducts for heat recovery and the inclusion of solar energy, in particular for modernisation
- part-mechanised, demand-led air-conditioning systems with heat recovery, also for modernisation
- glazed sun protection systems which can be automated using a large switch
- thermal component activation for space conditioning without damaging the room acoustics
- full substitution of boilers by heat pumps and CHP
- building control for the optimum integration of fluctuating energy supply and demand
- create commercially useful waste heat recovery using optimal local and district heating to an urban standard, and thus incorporate a district-related supply system which reacts to specific low energy demand
- increased use of low exergy technologies for residual heat demand

3.1.2 Electricity from renewable energy

Electricity from photovoltaics

In power generation in central Europe, solar cells from renewable energy sources have a very high technical potential. In some German states, the share of PV in electricity is currently already between 1 and 2%. The PV contribution to power generation is increasing rapidly worldwide. In the foreseeable future, this will lead to significant contributions to power supply through energy management. In the long-term, photovoltaics will form an important pillar of a sustainable energy supply system. In the last 30 years, prices for photovoltaic modules and photovoltaic inverters have already fallen by a factor of 10 (*Fig. 20* and *Fig. 21*) and this trend can continue further.

Since a final assessment of the different technological approaches with regard to the long-term development of photovoltaics is not yet possible at present, wide-ranging support for different technologies, with a focus on a rapid reduction in costs, is maintained, including crystalline si-photovoltaics (wafer and thin film), the conventional thin film techniques (amorphous silicon, Copper Indium Diselenid), as well as new approaches (organic solar cells and nanotechnology).

Photovoltaic inverters are one of the German PV industry's domains and are manufactured as a mass product. Using new semi-conductor materials such as silicon carbide (SiC) or gallium nitride (GaN), even higher efficiencies can be achieved in the future.

At the same time, costs fall as a result of higher levels of integration and more compact building techniques. As the rotating generators forming the network are increasingly omitted, inverters takes on more of the network control and stabilisation. They communicate with control centres and receive specifications from these centres for network operations.

Long-term research and development goals

- Photovoltaic module efficiencies achieve an average of 22%
- Increase in the life-span of modules through better understanding of the decomposition mechanisms
- Photovoltaic modules will be connected in an integrated way
- With all thin film materials, the thickness of the material amounts to only a few micrometres, and even with crystalline silicon this is below 30 µm.
- Cell and module production form one unit.
- The processed surfaces amount to several square meters. Thin film techniques (incl. crystalline Si-thin film techniques) achieve 20% efficiency.
  Photovoltaic modules act as a roof covering and thus reduce installation costs.
- Concentrated photovoltaics (CPV) achieve a module efficiency rate of 50%
- Photovoltaic inverters become more efficient, more compact and more cost-effective by using new semi-conductor elements
- Photovoltaic inverters take over network control tasks and are remotely controlled by control rooms
- Reduction in volumes of materials (semiconductors, metals, lamination, glass, connectors, encapsulation
- The costs of photovoltaic-generated electricity, even in Germany, are below the cost of electricity from fossil energy sources

Electricity from solar thermal power plants

Fast growing markets for solar thermal power plants are currently being developed in southern Europe, the USA and in some developing and emerging markets of the sun belt.
German industrial firms are involved in this as leading players. As well as the rapidly growing energy markets in the sunny countries of the world, there are already technical requirements now to also use the electricity produced there in central Europe, if the corresponding network capacity for high voltage-direct current-transmission (HVDC) is built.

In particular, the possibility of being able to integrate cost-effective energy storage or to produce electricity as needed through the co-firing of biogenic fuels, will in the long-term allow solar thermal power plants to meet large proportions of power demand.

Also, in conjunction with sea water desalination plants, solar thermal power plants show interesting potential to meet growing demand for power and water in the southern Mediterranean, in a cost-effective way.

The research themes on parabolic trough systems cover varied aspects of cost reduction and life span, as well as the use of new heat carriers with higher thermal stability and the use of direct evaporation technology, in order to achieve higher efficiencies in downstream power plants by an increase in discharge temperatures. The need for research into solar tower power plants goes much further, in basic work on improved or innovative receivers, and subsequent questions relating to the heat cycle at temperatures of up to 1000 °C.

Long-term research and development goals

The overall goal is to reduce electricity production costs by 50% and more, which should be achieved by following a number of different pathways:

- Enabling an increase in the efficiency of parabolic trough power plants through alternative heat transfer fluids e. g. steam or molten salt at operating temperatures of over 400 °C, increasing the overall efficiency
- Developing high temperature receivers for solar thermal power plants with varying heat transfer fluids (salt, steam, air, particles) for temperatures over 500°C
- Reduction in costs for concentrators using innovative reflectors, a more efficient tracking system and optimised design concepts for wind load
- Further optimisation of the operation and maintenance of solar thermal power plants
- A demonstration of the combined production of electricity and drinking water in North Africa at competitive prices

Electricity from wind energy

The expansion in the use of wind energy is mainly affected by two challenges. The highest growth is expected to be in onshore use. Here, the industry is facing the challenge of global market developments, while at the same time reducing costs, which requires technological developments with an emphasis on standardisation and the highest reliability in large-scale production.

An increase in research and development activities is also needed to expand wind energy use in emerging nations and developing countries. In particular, the specific climatic and topographical conditions (areas that are highly structured) are leading to new challenges.

One of the most important goals of research and development is further cost reduction through fundamental innovation such as, for example, further developments in systems engineering and the development of new materials and compound materials. In parallel to this, the aerodynamics, aeroelastics and aeroacoustics of the plants are further improved by the application of knowledge and instruments from fluid mechanics. Further research themes are an investigation of wind climatology, finding locations in complex terrains, and energy production estimates.

For offshore use there are additional challenges, which derive mainly from the higher loads from the wind and the sea and the more difficult accessibility. Innovative ideas for the overall system, regulations and technical reliability, as well as wind and wave characteristics for offshore applications, must be investigated.

Long-term research and development goals

- Wind energy plants are standardised, modularised and developed as technology platforms for large-scale production.
- The efficiency of wind energy plants is increased by 20%, while at the same time noise emissions are halved
- Wind turbines achieve an output of over 10 MW and have power plant characteristics
- The offshore use of wind energy is established as an important factor in power supply. Technical availability can be increased substantially.
- Accurate forecasting and effective energy management facilitate a reliable power supply from renewable energy sources.

Electricity from geothermal energy

The condition for a wider application of geothermal energy is the development of processes so that drilling can take place cheaply and safely, and the economic return on deposits can be increased in a targeted way. The research challenge is therefore to work on the learning curve towards the cost-effective supply of geothermal electricity. This should particularly include the development of so-called Enhanced Geothermal Systems (EGS). These are predominantly based on hot water deposits and dry geological formations, which are located outside the volcanic or tectonically active areas and are therefore associated with higher exploitation and/or production spending, in relation to recoverable energy. However, these reservoirs represent the main part of global deep geothermal potential and are also available in Germany.

Because the technology is still at an early stage, the preparation and success of the EGS research should in future be updated and expanded in appropriate programmes. In addition, Europe-wide research and development activities, national support programmes and competences should in future be brought together more and networked. The main emphasis for support and further development should be geothermal technologies which are not limited to particularly favourable areas for geothermal energy, and which are therefore transferable to similar situations world-wide, and which are exportable. Because of the existing technological synergies in conventional geothermal systems, the research successes will above all offer further export opportunities in the field of materials research and component selection.

Long-term research and development goals

- The development of cost-effective reservoirs should be achievable with only production and injection drilling, through improved planning and drilling feasibility, as well as a significant increase in the productivity of

geothermal reservoirs through innovative stimulation processes. The needs of the public are at the heart of considerations, so that "public acceptance" can be developed.
- The efficient conversion of geothermal heat into electricity
- Geothermal power production can be better planned economically when drilling costs are foreseeable and efficiencies are improved

3.1.3 Electricity and heat from fuel cells

Fuel cells are efficient energy converters, as they achieve particularly high electrical efficiency rates when there are especially low emissions of pollutants, and a high overall efficiency when there is simultaneous energy recovery. They can be operated using hydrogen, using hydrocarbon containing fuel cells (partly after reformation) or directly using methanol, and are suitable both for decentralised electricity and heat supply, and also for electric vehicle propulsion. Other promising possibilities for use are e.g. auxiliary power units in cars and planes, as well as replacing batteries in electronic equipment.

Long-term research and development goals
- Replacing electrode materials by using cheaper materials
- Alternative cheaper catalyser coating for electrodes
- Avoiding decomposition mechanisms in the stack
- Fuel cells will have a high power density and an operating period of 10 years and more, and offer cost-effective solutions for the stationary and also the mobile sectors

3.1.4 Chemical energy carriers from renewable energy

Energy recovery from biomass

Research and development in biomass is to be complemented by a scientifically based assessment of existing biomass potential, including biogenic waste, in terms of existing conflicts of use, issues of soil and nature conservation, potential production risks, technological restrictions and the social, ecological and economic implications of international biomass trade. In the long-term, as well as energy recovery from biogenic waste, efforts should be made for energy cascade use with (several) upstream materials processes for use in the area of cultivated biomass.

There is a particularly high potential for development for the combined use of biomass with a high overall efficiency: the optimised supply of electricity, heat and fuels through "polygeneration", which also opens up a CO_2-neutral substitution in the transport sector. When biomass is used for the production of synthetic gas, about 75% of the energy that is stored in biomass could already be supplied as hydrogen chemical energy. An important strategic question relates to contact with biomass-based local heat networks, as part of an increased expansion in building and heat insulation. Dynamic models should be developed in this context, which on the one hand would facilitate CO_2 -neutral heat supply as a temporary solution, but on the other hand would also provide sufficient incentives to carry out insulation measures in terms of reducing heat demand.

Long-term research and development goals
- The available biomass will be supplied, using biomass forecasting via satellite monitoring to optimise use, giving priority to the food chain and material use, and only finally to be used as energy (e.g. for fuels).
- Through the use of renewable resources "renewable electricity" and "biomass", biomass carbon is almost completely converted into carbon fuel.

Efficient production of hydrogen

The development of more efficient processes for the large-scale conversion of renewable energy into hydrogen is a requirement either for the establishment of hydrogen, and/or the production of renewable methane and its introduction as an energy source.

Producing hydrogen using electricity through the decomposition of water from renewable energy, seems – at least for central Europe – to be the most sensible option for hydrogen supply. The technologies required for this must primarily be developed for large-scale applications.

Concentrated solar systems offer an increasingly interesting possibility for countries in the sun belt. Here, sunlight is used in a direct thermo-chemical way to produce fuel cells. This process has the potential for very high conversion efficiencies: These so-called thermochemical cycles have the potential to be able to supply hydrogen at the highest efficiencies and the lowest costs. The first pilot plants are under construction. To develop further, materials and components must be available which allow the plants to be operated at temperatures of over 1000 °C.

Implementing direct water splitting using cata - lytic connections is also an important option. Cost-effective materials must be developed for this in order to produce the hydrogen.

Long-term research and development goals

- Replacement of precious metals by cheaper materials for water electrolysis
- Hydrogen production using solar-supported thermochemical reactions supplement hydrogen production by electrolysis, or by high pressure or high temperature electro-lysis.
- Solar fuel cell production, especially using hydrogen with the use of biological conver-ters or nanotechnological tailor-made cataly-tic materials. An electrochemical reduction in CO_2 using methanol and methane is also a worthwhile research aim.
- The storage of hydrogen or 'biomethane' in caverns to smooth out fluctuating renewable energy plays an important role for large-scale energy storage, upwards of several hundred GWh.

Efficient production of methane

For power storage in Germany there are cur-rently almost exclusively pumped storage plants with a storage capacity of 0.04 TWh. However, for full renewable supply, about 20 TWh is nee-ded. These high storage capacities can only be provided using chemical energy carriers. As well as hydrogen, renewable methane as a natural gas substitute (Subsitute Natural Gas) is the most interesting option, as the existing infra-structure and the existing storage capacity of > 200 TWh can also be used for this. This new storage concept should therefore be brought to market by increased research and development.

The process chain for producing renewable methane from electrical energy, water and CO_2 consists of the two main components, water electrolysis and methanation.

Further advances should be made in methane synthesis and the integration of renewable me-thane into the energy system.

Long-term research and development goals

- Electricity and renewable methane can each be converted into the other and have a fully developed infrastructure, so that the storage capacity of the gas network can also be used for seasonal storage in the electricity sector.
- Renewable methane gas and renewable fuels from wind, solar and hydro power are produced highly efficiently; decentralised and centralised plants are available in the market.

3.1.5 Using CO_2 as a raw material

The CO_2 capture and storage which is currently under investigation presents a conventional 'End of pipe'- technology, which does not itself change the production process, but only seeks to reduce environmental damage downstream. Even if successful, only very limited amounts of CO_2 can be kept out of the atmosphere. It is more promising and above all more sustainable to use CO_2 as a raw material for the chemical industry, for the production of renewable methane and subsequently for every kind of synthetic material [38]. More economic, more ecological and more socially beneficial are also global reforestation and the build up of humus, which extracts greenhouse gases from the atmosphere. This can counter soil erosion and damage and thus provides a dual use for growing food and for energy crops.

Long-term research and development goals

- Increase in the supply efficiency of CO_2 methanisation

3.1.6 Energy storage

In almost all areas of energy technology, “energy technology“ can be significantly reduced by storing energy, and many worthwhile process improvements are possible for the first time by using storage. Energy storage is thus the central component for a sustainable energy economy, which is relevant for all three strands of energy policy:

- A reduction in final energy consumption
- An increase in energy conversion and supply efficiency
- An increase in the share of renewable energy in the energy mix

In the past, developments in energy storage were scarcely promoted. This applies both to storage for electrical energy (batteries), and to thermal storage and chemical storage (alternative fuels). New fundamental technological approaches must be developed in all areas and new research capacities must be established. The work ranges from very fundamental aspects to applications and require the cooperation of very different scientific disciplines. In parallel with research and development, the market introduction of storage or the implementation of optimal energy systems must be promoted.

Electricity storage

The need for electrical energy storage (fuel cells and batteries), electrochemical storage (high temperature and redox flow batteries) and hybrid systems with batteries and super-condensers with high power densities and long lifetimes will increase significantly in the next few years. This is because the share of electricity from decentralised and fluctuating sources will increase, which will speed up the stationary use of these technologies. At the same time, their mobile application in transport will become increasingly important. Research and development can contribute towards making up the deficit that has arisen here in the last few years.

The challenges lie in a user-friendly cost structure for electrochemical storage and the production of application-oriented system solutions. This applies in particular to stationary electrochemical power storage for the fluctuating feed-in from PV and wind plants. Here a development is emerging by which surplus wind power is directed into large battery systems in order to integrate these into an energy service system, which efficiently stabilises voltage and frequency in the distribution network.

Long-term research and development goals:

- Batteries and cells have a high energy and power density, which helps electromobility to penetrate.
- The decentralised storage of electrical energy in high temperature or redox flow batteries is efficient on the flat
- The number of large compressed air stores will be increased five-fold
- Fluctuating accumulating renewable electricity can be converted by storage in the form of renewable methane as required, thus facilitating planning.

Heat storage

Extensive research and development work is required for new storage techniques. Through the development of new storage materials on the basis of phase transformation and sorption materials, in principle, completely new approaches to heat storage, with low storage losses, are possible, which enable higher energy densities and support the use of decentralised heat supply systems. Reduced energy consumption in modern buildings makes this kind of new approach particularly promising from the viewpoint of system technologies.

New storage materials also open up new opportunities for use in the field of high temperatures for solar thermal power plant technology, and for the improved utilisation of industrial process heat. In this context, storage for small combined heat and cooling plants is of interest, as with these components an optimal power-led operation is possible and the accumulated heat can be stored for up to a few days. With solar thermal power plants, the availability and electricity production costs can be significantly improved by installing heat stores.

Long-term research and development goals

- New materials, components and systems allow heat transmission to be controlled in a targeted way, i. e. to facilitate and accelerate it, or to reduce and delay it.

Seasonal geothermal heat stores

The seasonal storage of thermal energy in aquifers, as well as the integration of storage into energy supply systems, has enormous potential which until now has been insufficiently taken into account. The combination of seasonal heat storage and combined heat and power (CHP) also improves the demand-led power supply of an energy system. By storing surplus heat in times of low heat demand, CHP plants can be operated all year to produce electricity, as the stored surplus heat can be used when there is a higher demand for heat. Here, aquifer heat stores are particularly well suited because of their high storage capacity and high heat recovery rates during seasonal operation.

Aquifer cold storage allows low winter temperatures to be used for cooling in summer. In comparison with conventional cooling supply, significantly higher COP values (Coefficient of Performance) are achieved for cooling supply (factor 5 to 10), which allows the electricity demand for cooling supply to be reduced in particular during the summer months. The use of aquifers as thermal energy stores is determined by geological ratios. In Germany, about 70% of the surface area is generally suitable for the use of stores with a capacity of 5-10 GWh each, as is used for example in the parliament's building in Berlin. With an assumed number of 2000 plants in Germany, a storage capacity of over 10 TWh is possible.

Long-term research and development goals

- Despite good experience with the previous projects, there are constraints on converting further stores, which is caused by the complexity of the planning process and by systems engineering. Basic technological consolidation is required, from which planning and operating guidelines will be developed, which are based on experience gained from pre-competitive demonstration projects with a recognisable research component. The resulting standardisation of the planning, construction and operation of energy supply systems with aquifer stores is essential to create high potential.

3.1.7 Heat and cooling from renewable energy

Heat and cooling from solar thermal collectors

Solar thermal collectors convert the solar radiation received into heat. It can be used with various technologies in different temperature areas:

- Solar thermal flat plate or vacuum tube collectors heat tap water and drinking water for households and for space heating.
- Concentrated solar collectors (parabolic trough and linear fresnel systems) or high efficiency flat plate collectors provide process heat at higher temperature levels, ready for industrial applications and air conditioning in buildings.

Collector systems to produce heat up to 90 °C must be further developed in order to reduce costs and open up new applications. This is particularly the case for integrating solar collectors into the building envelope. This is a condition for developing systems engineering for the solar active house, whose heat demand is fully met by solar heat, and as an intermediate step for the "Solar house 50+", over 50% of whose heat demand is met by solar heat.

On the basis of solar thermal collectors, complete systems for combined heat and power are constructed, which in the summer half of the year are largely solar-driven, while in the winter half of the year they produce electricity using renewable methane or biofuels, and feed the waste into a heat network. Economic optimisation – efficient renovation compared with the use of waste in local heating systems – is also an important subject for research.

Long-term research and development goals

- Despite good experience with the previous projects, there are constraints on converting further stores, which is caused by the complexity of the planning process and by systems engineering. Basic technological consolidation is required, from which planning and operating guidelines will be developed, which are based on experience gained from pre-competitive demonstration projects with a recognisable research component. The resulting standardisation of the planning, construction and operation of energy supply systems with aquifer stores is essential to create high potential.

Heat and cooling from geothermal energy

The important task for research and development is to prepare this technology in a reliable way. For a more cost-effective and efficient supply of geothermal energy, there should be an increase in the seasonal performance factor (ratio of thermal heat to power) of geothermal plants. Depending on the heat source used, in small plants, improvable seasonal performance factors of 3 (ambient air) to over 4 (geothermal probe/water) are achieved – in combination with low-exergy-heating surfaces significantly better values are achievable. Larger supply systems should be improved by the cost-effective seasonal storage of heat and cooling underground. Heat sources deep underground must be developed more economically.

Long-term research and development goals

- Increase in the seasonal performance factors (ratio of thermal heat to power) of geothermal plants
- Development of suitable heat transfer over days, e.g. in low temperature heating networks and the direct use of heat

3.1.8 Mobility

The climate problem requires new methods of mobility. Developing technologies for battery- and fuel cell-supported electric vehicles results in extremely energy efficient electric power systems with efficiencies of up to 80% (from store to drive shaft) and offers the possibility of providing the energy supply for transport from renewable sources such as solar or wind energy.

The Energy Concept 2050 regards electromobility and the development of more cost-effective and reliable stationary electricity storage as an opportunity for Germany to move forward economically and ecologically into a new dimension. With the necessary change in technology in the mobility sector, there is also the opportunity not only to adapt our current energy system, but to structurally transform it.

The future electric car will consist of a technological combination of fuel cells, batteries and super-condensers. For this reason it is necessary to further develop battery and fuel cell technologies in parallel, and to research the potential for the hybrid mode of operation, as only by developing these technology pathways is it possible to transform the mobility sector and to be international leaders in technology. The different storage technologies will be coupled with traction through highly efficient compact power electronics. Intelligent plant management will decide how the load is allocated to the different stores.

As well as research in the field of battery systems engineering, suitable energy systems and system components must also be developed for power electronics and control engineering.

Long-term research and development goals

- The efficiency of electric motors reaches 98%
- Inductive power transmission is installed in many streets
- Passenger cars are largely electrified and charge their on-board energy store with power from renewable energy or hydrogen, methane or other renewable fuels – produced from wind, solar energy and hydro power
- Surpluses from renewable electricity generation are supplied to the transport sector in the form of renewable fuels (hydrogen, methane, dimethyl ether, kerosene, etc.) via the energy infrastructure.
- Super-condensers can supplement systems with low power density in such a way that in the short-term as well, high output can be realised. This allows a particularly favourable system design. However, a broad introduction requires a further increase in energy densities, with power densities that are adapted for use.

- Highly efficient, compact and bi-directional frequency converters must be developed to charge the batteries of electric cars with as few losses as possible, and at the same time to be able to integrate them into the network as quick energy storage. The charging infrastructure and the vehicle network interface should be developed, with the aspects of identification, metering, invoicing and communication (between the vehicle, the network and the user).
- The challenge for safety techniques relating to lithium batteries is the absolute avoidance of a "thermal runaway". At the same time, however, the cells must be able to be charged quickly. This requires a detailed understanding of the thermochemical mechanisms, the best thermal management design, as well as the development of thermally stable electrode materials.

3.1.9 Electrical systems engineering, network management and distributed power plants

The aim of future research and development efforts must be to design changing supply structures in such a way that network stability and security of supply continue to be assured with a growing number of fluctuating suppliers, even without large reserves of power. The inverters of wind and PV plants must take on network creation functions and safeguard security of supply. The network that is today formed of rotating generators will become a power electronics, inverter-led network.

Power transmission and energy balancing at German and European level plays a key role for the use of fluctuating energy sources. The central themes are network expansion, network control and the optimal integration of renewable energy using power electronics energy converters, which are actively involved in network control and which safeguards network stability. Here, efficient communications structures, online- and forecasting processes for network resource scheduling, as well as bi-directional energy management and trading systems, are of particular importance for the dialogue between the energy producer, distributor and consumer.

Renewable producers can therefore take over all the necessary system services for secure network operation from conventional power plants. Here, it is essential to develop modern information and communications technology for improved energy management processes. A key role is played by the dynamic network simulation for the European area and beyond. Only with the help of these simulations can the effect of the planned expansion scenarios for renewable energy in Europe, the varying integration strategies for pumped storage plants and the level of expansion in the European transmission network be analysed in relation to security of supply and the cost of energy supply.

Long-term research and development goals

- Smart grids will be introduced everywhere and will communicate with the smart control devices[12] in the building
- Long-range power transmission using HVDC technology will have become established by 2050 and will help to distribute electricity from renewable energy sources
- Efficient medium and high voltage converters will be developed, to be coupled with direct and alternating current networks
- New control methods for network stability for the power electronics-led network will be developed. The power flows between the alternating current network, the direct current network and energy stores will be controlled intelligently.
- Power transmission with superconductors will be used in areas with high power demand.
- Electricity, gas and heat networks will be optimally networked and expanded as economically as possible

12 Smart control equipment consists of e. g. bi-directional energy management interfaces (BEMI)

3.1.10 Systems analysis and assessment of technological implications for financial incentives and the requirements of political regulation

The development of new energy technologies takes place within a complex environment with numerous technical, economic, ecological and energy policy conditions.

The requirement for a successful market introduction is therefore a preliminary and related analysis of these relationships. Here systems analysis applies. Using analyses of potential, the future prospects for new energy technologies and systems will be explored. Subsequently, scenarios will be drawn up which present possible pathways for development. Converting these scenarios through the targeted use of political instruments, their specific adaptation, modification or reorganisation, and the accompanying political debate, are some of the fundamentally important starting points for system-analytical work to achieve this conversion.

During the conversion phase, energy technologies and systems, as well as the selected funding instruments, are accompanied by monitoring. Systems analysis and an assessment of the results of technology will be needed to adapt political concepts to unexpected developments. This continuous and comprehensive evaluation identifies opportunities and risks, helps to detect possible mistakes in good time, and develops alternative approaches. Consideration should be given to economic aspects – such as the liberalisation and globalisation of the energy markets –, ecological aspects, questions of supply security and also the requirements of international climate protection policy.

3.1.11 Supplementary social research

One of the most important fields of research consists of supplementary social research, in particular, the question of acceptance for new technologies and processes to improve the dialogue between technology and the user must be developed. Consideration of this aspect is especially important for realising a North African-European power network.