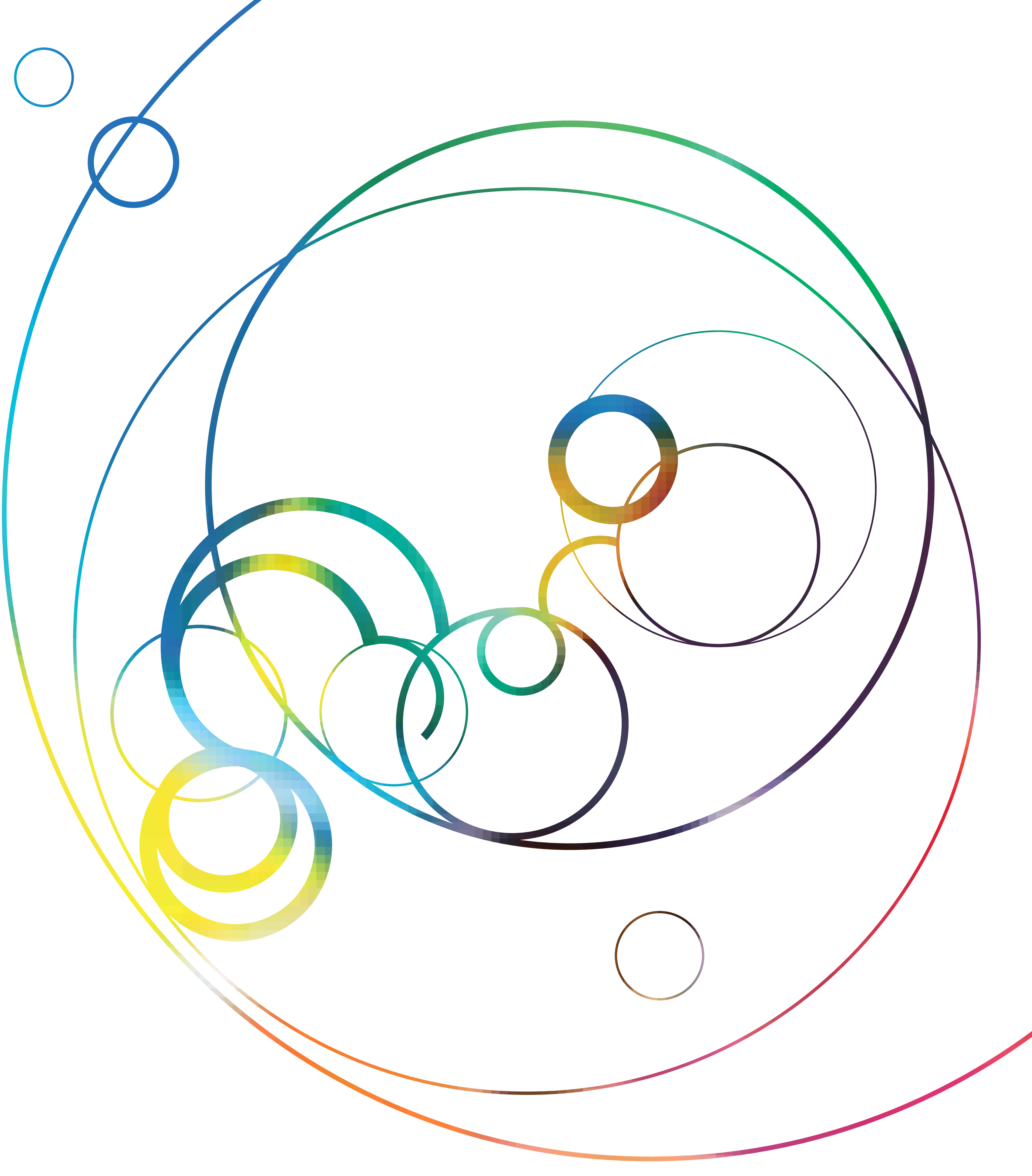


RESEARCH PRIORITIES FOR RENEWABLE ENERGY TECHNOLOGY BY 2020 AND BEYOND

Europe Direct is a service to help you find answers to your questions about the European Union

Freephone number (*):
00 800 6 7 8 9 10 11

(*) Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

More information on the European Union is available on the Internet (http://europa.eu).

Cataloguing data can be found at the end of this publication.

Luxembourg: Office for Official Publications of the European Communities, 2009

ISBN 978-92-79-11948-4

Printed in Belgium

Printed on white chlorine-free paper

RESEARCH PRIORITIES FOR RENEWABLE ENERGY TECHNOLOGY BY 2020 AND BEYOND

TABLE OF CONTENTS

INTRODUCTION

In 2005, as an input to the discussion on the Seventh Framework Programme for Research and Development, the EUREC Agency published a report on Research Priorities for the Renewable Energy Sector. As an association of leading European research centres working across the full range of renewable energy technologies, the EUREC Agency was able to bring together and summarise the research required in the renewable energy sector in a single document.

Since then, the move towards widespread implementation of renewable energy across Europe has accelerated and several measures have been taken at EU level with a view to establishing a New Energy Policy for Europe, in particular:

- The European Commission adopted, in November 2007, a Communication on the Strategic Energy Technology Plan (SET-Plan), which aims at launching a series of initiatives at European level to boost private and public investments in energy technologies.
- In December 2008, the European Parliament and the Council adopted the so-called "Climate and Energy Package", a crucial legal framework marking a decisive step forward for the development of the renewable energy sector. Amongst the other measures, it contains a new Directive on the promotion of the use of energy from renewable sources which is geared towards achieving a 20% renewable energy share by 2020 with individual renewable energy targets binding for EU Member States.

With the new emphasis on rapid implementation of renewable technologies to achieve the 2020 targets, the EUREC Agency decided to revisit the research priorities in terms of how research can and should contribute to the achievement of those targets. Whilst the research itself provides the means to achieve the European ambitions in the development of renewable energy, it should also be recognised that it provides an important educational tool for the training of the highly skilled workforce who will design and implement the new energy systems of the future.

The document has been structured according to the three sectors discussed in the Directive, namely electricity generation, heating and cooling and renewable energy in transport. In practice, each of these targets will be met by a range of renewable technologies and this approach has allowed us to draw out the cross cutting research themes in each case. The document does not specifically address energy efficiency, which is another central theme of the 2020 targets. Nevertheless, the importance of the reduction of energy demand is fully recognised and supported by the EUREC Agency as a necessary complement to renewable energy generation.

The research priorities presented have been defined on the basis of a broad consultation involving the scientific community of renewable energy research centres represented at European level by the EUREC Agency. They include input from relevant industry associations and take account of the Strategic Research Agendas published by a number of European Technology Platforms focussing both on renewable energy sources (Biofuels, Wind Energy, Photovoltaics, and Solar Thermal Heating & Cooling) and related technologies (Electricity Networks of the Future, Construction, Hydrogen and Fuel Cells).

This publication primarily considers where research investment should be focused in the coming years in order to reach the 20-20-20 target. High potential technologies beyond 2020 have also been identified to stress the importance of investing in long-term research as a way to enable cost reductions in the conversion technologies and make sustainable energy supply systems increasingly convenient and reliable.

ELECTRICITY GENERATION FROM RENEWABLE ENERGY SOURCES

A. INTRODUCTION


© Shell

The European electricity supply industry is facing challenges as never before. National, European and worldwide energy policies are pressing for the provision of electricity which is both sustainable and affordable to all whilst accommodating economic growth. These challenges may to some extent conflict and different countries may have different priorities which make accommodation of all of these areas difficult. Some of the challenges are common to all forms of power generation and some present specific problems to renewable energy generation. Renewable energy generation has the potential to provide sustainable electricity but may present problems with regard to cost in the short term. There are many factors which influence the viability of renewable electricity generation across Europe and beyond and consideration of regional issues is important.

It is clear that sustainable electricity provision must be tackled both from the generation and the demand side. Passive and unconstrained consumer demand is no longer an option if renewable energy generation is to be accommodated on a large scale. The evidence of climate change to some extent is inevitable. Only the scale of this over the next century is in doubt. This will affect many areas of the economy including electricity demand, the electricity network and the renewable energy resource. An assessment of these factors will be important to see how the large-scale deployment of renewable energy generation will fit into a future electricity supply system. The projected electricity demand growth must be assessed initially to understand the scale of the challenge for renewable energy and the measures that may need to be taken to make electricity demand growth sustainable.


© Phoenix Sonnenstrom

Research into both the technical fixes and the socio-economic measures that will best facilitate high penetrations of renewable energy generation is required. Technology could help to make consumer demand more controllable and dispatchable by the use of smart metering and deferrable loads. This has the potential to accommodate variable renewable energy generation. This can only go so far, however, and research into consumer behaviour and responses to "carrot and stick" approaches to managing individual consumption is required.

In the medium term, the way that renewable energy generation interacts with conventional generation and how electricity from renewable generators may be transmitted through the transmission and distribution networks is important. Much has been made of the role of electricity storage in the accommodation of large penetrations of variable renewable energy generation. However, in the medium term storage is likely to remain expensive and unlikely to be cost effective compared with other options. Research is required to make storage options economic in the medium to long term. One major option is the potential to aggregate different forms of renewable energy generation over large geographical areas and the flexibility to transmit power from renewable generators over long distances.

There are a number of research challenges here which need to be addressed including:

- Mitigation of line losses;
- Understanding the regional resource for different renewables;
- Managing system stability over long distances;
- Understanding and mitigating network constraints;
- Managing conventional generation plant (fossil and nuclear) to work with renewable generation;
- The move from centralised to decentralised (distributed) generation;
- Developing improved demand side management systems;
- Developing a truly trans-national trading market for electricity;
- Development of dispatch strategies that are based on renewable resource forecast and storage options;
- Identification of grid extension requirements to achieve a penetration of renewable electricity in combination with secure supply.

The different renewable energy generation sources are at different stages of maturity in relation to the electricity market and require different levels of research and development. These relate to:

- **The resource:** this may vary widely and be more difficult to assess in certain environments, climate change may change the resource in the future;
- **The technology:** in some cases, this is mature and needs to be made more reliable or more cost effective, but in other cases, it is not yet proven and requires further development;
- **The interaction with the grid:** how each form of generation may interact with the electricity network is critical if large penetrations of renewable energy are to be realised.

B. EUROPEAN ELECTRICITY SUPPLY AND DEMAND

1. Generation, Network Infrastructure and Storage

Background

As it is not always possible or efficient to produce electricity close to where it will be consumed, electrical distribution systems will play a very important role in the future development of renewable electricity given that the areas of greatest resource are often to be found far from centres of population.

© Norskhydro

The reinforcement of the grid should include the deployment of technologies such as FACTS (Flexible AC Transmission Systems), WAMS (Wide Area Monitoring Services) and the possible adoption of HVDC (High Voltage Direct Current) transmission technologies, or possibly gas-insulated AC transmission technology where geographical circumstances make it appropriate. AC was adopted as a standard over a century ago, when the electricity production and consumption schemes were rather different from today's. DC is better suited to transporting power over long distances, especially underwater, and will favour the further development of off-shore wind energy.

In the medium and long term, electricity storage devices will play a key role in matching electricity supply with electricity demand over different timescales. Batteries are already being used on electricity systems in several countries to store small quantities of electricity over periods of a few hours and their presence on the grid may increase rapidly if cars with high capacity batteries are sold in significant numbers. Other technologies could provide storage over much shorter time spans, e.g. flywheels, Superconducting Magnetic Energy Storage (SMES), useful in power quality management, or over longer periods. e.g. compressed air storage, pumped storage or hydrogen (for more on this topic please see further in the section "Renewable Energy in Transport applications").

Research and Development Challenges:

- Maintaining security of supply with a high penetration of renewable energy;
- Moving from a passive to an active "smart" distribution network;
- Mitigating against transmission and distribution losses;
- Managing fluctuating energy sources efficiently as well as developing cost-effective electricity storage;
- Developing new business models to encourage the uptake of renewable energy and the dynamic participation of consumers;
- Developing new standards and grid codes to remove existing barriers for high penetrations of renewable energy sources (RES).

High temperature superconductors (HTS) could be a key technology in addressing these broad challenges in the long term, i.e. beyond 2020:

- HTS devices could improve reliability and reduce costs of key components for renewable electricity production;
- HTS cables could contribute to reducing transmission losses and to increasing the capacity of electricity transmission;
- SMES (Superconducting Magnetic Energy Storage) based on HTS materials could be a key technology for the development of electricity storage systems for a better integration of RES.

2. Demand Side Management

Background

On the demand side, research priorities should focus on smoothing out the electricity demand curve which will enable dispatchable generating capacity to work at optimal efficiency. One way to achieve this is to make load more flexible.

The least sophisticated technique to manage demand would be one where the end-consumer regulates his or her own electricity demand. For this to happen, electricity meters that report to the end consumer the real time costs of electricity are needed, and an effective way of displaying this information must be found, e.g. the location of the price and consumption display in the dwelling must be carefully chosen.

Another potentially low-cost way to regulate demand is to incorporate chips into appliances that respond to the grid frequency. Pilot experiments were conducted on the employment of smart devices programmed to react to the grid frequency shutting off temporarily given elements in the connected appliances in order to shed loads at times of heavy demand. This technology, if further developed and widely adopted by consumers, could act as a "shock absorber" for the grid when demand peaks, helping to reduce the number of power cuts and brownouts.

More innovative models of electricity demand management will most probably rely on the widespread adoption of electricity meters that can automatically regulate the consumption of appliances installed in a consumer's home in response to price signals.

Research and Development Challenges:

- Understanding human behaviour in response to DSM incentives;
- Development of smart metering and smart control systems to move towards more dynamic pricing regimes;
- Development of "intelligent" consumer devices that can react to external signals.

C. RENEWABLE ENERGY RESOURCES [1]

1. Wind

Background

The deployment of wind turbines is now moving to more challenging environments. There is a major drive to place wind turbines offshore with all the problems that a harsh marine environment entails. Increasingly, wind farms are built in areas of complex terrain and additionally in areas in or close to forested areas. Although the resource is less attractive, there is also an increased interest in wind energy in the built environment to help make buildings more energy self-sufficient. This gives rise to new technical, environmental, and policy challenges.

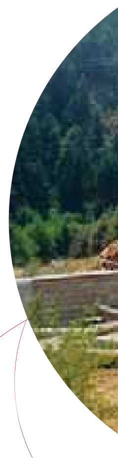
[1] Renewable energy sources are listed in decreasing order here according to the installed capacity in 2006 (Eurostat data)

Research and Development Challenges:

Offshore

The main challenge here is to produce cost effective electricity from reliable machines. There is therefore a requirement for research in the following areas:

- A better understanding of the environmental conditions including wind and wave loading;
- A better understanding of the impact of wind farms on the marine environment;
- Better models of the wind turbine structure;
- Study of the support structures, blades and drive train to better understand the loads and to develop new materials to make these components cheaper, lighter and more reliable;
- Better strategies for installation;
- Improved operations and maintenance including the enhanced role of condition monitoring;
- Better understanding of large wind turbine array interactions;
- Improvements in grid connection issues e.g. reducing costs, simplifying cable deployment, investigating different topologies for connection to shore, improving cable efficiency by use of such as HTS, DC connections, etc.
- Better understanding of the risks involved in offshore development;
- Development of new industry standards for offshore wind energy;
- Development of the regulatory requirements which are less burdensome and are based more soundly on the technical, environmental and social constraints.



Complex Terrain/Forests

A better understanding of the environmental conditions is required including:

- The development of flow models for complex terrain, e.g. tailoring of computational fluid dynamics (CFD) models for use in wind resource assessment including thermal effects;
- Measuring and predicting levels of turbulence;
- Developing and validating the use of remote sensing equipment for resource estimation including the use of lidar.

Built Environment

Here the challenge is to better understand the resource and to develop turbines for the urban environment. Specific challenges include:

- Downscaling wind atlases for use in the urban environment;
- The use of CFD to understand wind flow and turbulence on and around buildings;
- Developing wind turbines to maximise yield and to cope with high levels of turbulence;
- Developing new buildings to integrate wind turbines in the built environment.

2. Biomass for Power Generation

Background

Demonstrating the functioning of highly reliable, complete biomass supply chains over the long term for a variety of communities with differing local resources is a priority. The outcomes of these demonstration projects should enable models to be created that compare the demand for heat, power and biofuels with feedstock availability and enable cost-effective routes to biomass exploitation to be found.

With regard to research on the feedstocks for these chains, an important area to focus on is the demonstration of viable energy crop production methods that obtain higher yield, while minimising fertilizer/pesticide requirements and their associated negative environmental impacts. Research into the production, collection and pre-processing of other key feedstocks like agricultural forestry residues and biogenic municipal solid waste is also needed. The interaction between biomass-for-energy markets and markets that use agricultural products for non-energy purposes like food supply must be better understood, as should the environmental and social impact of the significant changes in land-use that may be likely if biomass is promoted widely across the EU.

Gasification

Advanced gasification processes should be developed for power and hydrogen and/or syngas production using biomass-fired integrated gasification combined cycle turbine plants. Gasification needs to be demonstrated for small-scale, decentralised applications.

Research and Development Challenges:

- Developing fuel supply chains;
- Developing high yield crops resistant to disease and pests;
- Improving pre-processing of feedstocks;
- Analysis of and mitigation against the potential conflict between food and fuel crops;
- Development of gasification processes, including the cost-effective production of hydrogen and syngas.

3. Hydro (Small Hydropower)

Background

Much of the large scale hydropower resource within Europe has been developed. Furthermore, the adverse environmental impact of large scale hydropower schemes makes such developments unattractive. The research challenges are now focussed on developing small hydro sites where the head and/or flow rate may be quite small. This means the development of low cost low-head hydro turbines with efficient generators. Much of the cost of a small hydro scheme is in the supporting infrastructure and it is here that cost savings must be made, e.g. by the development of low-cost effective automatic trash rack systems.

© IT power

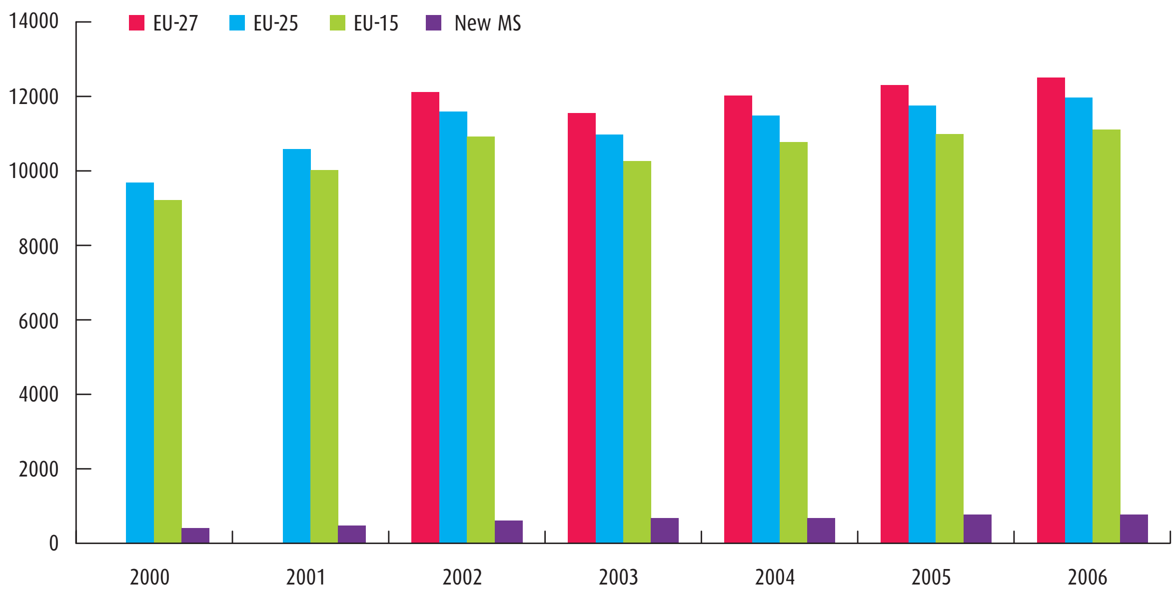


Figure 1: Installed Capacity of Small Hydropower (up to 10MW) in MW [2]

Research and Development Challenges:

These challenges may be summarised under a number of categories:

Generators and Electrical Engineering

- Development of better low speed direct-drive generators that are suitable for low heads (<5m). These could find a use also in overtopping wave energy devices;
- Development of better generators through the adaptation of high pole permanent magnet excitation generators to small hydro applications;
- Development of submersible turbo-generators.

Mechanical Engineering (Turbines)

- Development of turbines with very low environmental impact, building on the example of bulb-turbines using permanent magnets;
- Improvements in the construction materials for the turbine's moving parts and the parts of the small-hydro installation exposed to water, e.g. using new alloys, or lighter, longer lasting, cheaper and stronger alternatives.

Civil Engineering

- Techniques to custom-design for a given site the heavy, load-bearing concrete structures that enclose small hydro plants should be available that result in enclosures that cost no more than standardised enclosures. In this way, water flow may be improved at the site and its electricity output increased;
- Research into more efficient desilters with high head intakes, and self-cleaning water intakes and trashracks;
- Development of methods to increase the water head at very low head sites while causing minimal environmental disruption.

[2] Data provided by ESHA – the European Small Hydropower Association. There is no international consensus on the definition of small hydropower (SHP). In China, it can refer to capacities of up to 25 MW, in India up to 15 MW and in Sweden small means up to 1.5 MW. However, a capacity of up to 10 MW total is becoming the generally accepted norm by ESHA, the European Commission and UNIPEDE (International Union of Producers and Distributors of Electricity).

Environment

The above civil engineering improvements should be part of a suite of integrated design rules that:

- Take local environmental issues into account, including, with regards to fish, the development of screening processes for downstream and upstream migrating fish (fish passes, fish guiding systems);
- Assure that correct minimum residual flows from hydropower plants and flow conditions are satisfied for each site.

Hydrological assessment methods need to be improved. This involves the development of low cost but efficient measurement techniques and hydrological site evaluation software.

Standards and Monitoring

- Standardised tests of small hydro plant performance and its monitoring over the long-term will offer insights that enable reliability to be increased.
- Site developers need clearer guidelines, perhaps in the form of a software toolkit for project design.

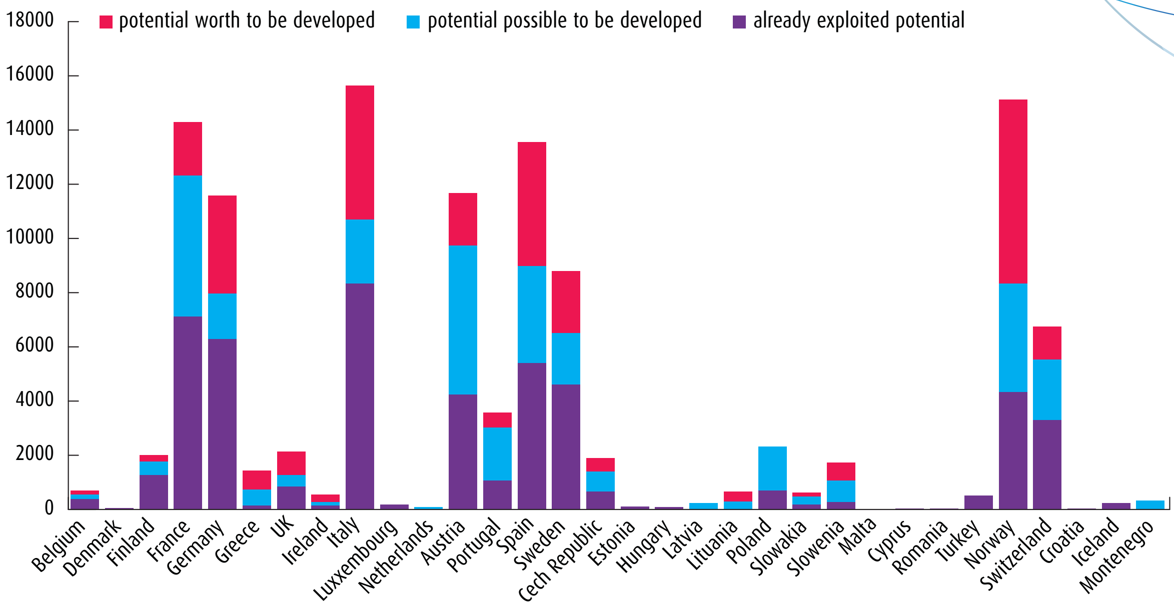


Figure 2: Potential of electricity generation from SHP in Europe (source ESHA)

4. Solar Photovoltaic

Background

Although reliable, high-performance and low-cost PV systems are commercially available and widely deployed, further development of PV science and technology is crucial to enable PV to become a major source of electricity and energy in the world.

Ambitious further development of PV technology is fundamental to reduce the cost of solar electricity and to enable PV to become a major source of sustainable energy. The corresponding PV system price targets are very important for the rapid and broad development of PV. Very large-scale implementation of PV is only feasible if PV generation costs are drastically reduced. The current price level of PV systems is very competitive but it does not yet allow direct competition with consumer or wholesale electricity prices except in a few places in the world.

Primary research issues are reducing the costs and increasing the performance of PV technologies, but the importance of other drivers have to be emphasized as well. These include the lifetime of PV system components, energy and materials consumption in manufacturing and installation, the reduction of the energy pay-back time of systems, substituting the use of scarce, hazardous, rare and expensive materials, standardisation and harmonisation, flexibility in system design and lightweight substrate technologies (i.e. for roll-to-roll-production). Socio-economic aspects such as public and political awareness, training and education, user acceptance and financing, can also have a significant impact.

There are two approaches possible:

- To pursue the high-efficiency route while reducing the module cost;
- To produce a solar cell as cheaply as possible, because even if it has a low conversion efficiency, it will still be a low-cost way to produce electricity.

Research and Development Challenges:

PV development options in cell and module technologies which require further research include:

Existing Cell Technologies

- Wafer-based crystalline silicon; in particular reducing the cell thickness and implementing advanced cells design, e.g. selective emitter, rear contact cells, etc.;
- Existing thin-film technologies; in particular emphasising the research activities on bottlenecks such as interfaces, intra-grain defects, interconnections, etc.;
- III-V multi-junction and concentrator technologies; in particular simplifying the multi-junctions formation, studying the mismatching and the tunnel layers.


© Bundesverband Solarindustrie

Emerging and New PV Technologies:

- Advanced inorganic thin-film technologies with emphasis on high growth rates, stable and reliable materials as well as increased cell efficiency through innovative device structures;
- Organic solar cells, based on polymers, molecules, dye sensitized and hybrid cells;
- Thermo-photovoltaics;
- Novel PV-technologies;
- Novel active layers;
- Tailoring the solar spectrum to boost existing cell technologies; in particular, the use of nano-dots and nano-wires to improve photon conversion, i.e. down conversion, up conversion, multi-generation of excitons, and their implementation in conventional or advanced cells.

Components and Systems

- Reduction in the cost of PV systems including power electronics, grids, rural electrification systems, etc.;
- Multifunctional inverters, which can contribute to the stability and quality of the electric grid.

Urban Environment

- Developing PV construction materials to replace conventional types. Cost analysis should consider two functionalities: the use of the components in producing the unit; and the production of electricity;
- Integrating distributed data acquisition and monitoring systems to improve the efficiency of whole systems, including operation and maintenance costs.

5. Geothermal

Background

Geothermal research is generating results that can be applied in other domains, for instance, in material durability, using experimental data from the exposure of components for long periods to the hot water from the bottom of the bore. Experiments are currently underway to demonstrate the production of geothermal electricity from heat stored deep underground in a variety of rock formations. Increasing the thermodynamic efficiency of low temperature electricity generation cycles (e.g. Rankine or Kalina) is also an active area of research. The opportunities for cost reduction in deep medium- to high-temperature geothermal thermal systems are to be found in exploration, drilling, reservoir stimulation and heat to power conversion.

Exploration and the identification of sites suitable for geothermal bores requires improved tools for resource mapping, a better understanding of techniques to prolong the lifetime of existing boreholes and the re-interpretation of existing geophysical, geological and geochemical data to identify patterns that suggest the presence of a good resource below ground. Numerical models of geothermal bores must be improved to better predict the bores' long-term behaviour.

Two thirds of the costs of geothermal plants are associated with drilling the wells. Great advances are possible in drilling technology, such as "micro-drilling" for exploration and preliminary resource assessment, and laser drilling and fusion drilling for drilling the main borehole.

The stimulation of the bores, which means the fracturing of rock to increase the amount of rock surface in contact with the water pumped down from the surface, must be improved and the fractures' creation, maintenance and possible restoration must be checked automatically and constantly. In-situ measurement technologies should be developed, perhaps using fibre optic cables and tomography. It is suggested that a slim-line high temperature directional borehole radar be developed to investigate the structure and extent of usable geothermal strata. Monitoring of cracks through micro-seismic and passive seismic techniques, through electrical potentials and through kinetic and chemical processes also needs to be increased.

Finally, extending the resources far beyond a conventional use of geothermal fields requires the use of non-conventional methods for exploring, developing and exploiting resources that are not economically viable by conventional methods. For instance, the Enhanced Geothermal Systems (EGS) concept covers specifically reservoirs at depth that must be engineered to improve hydraulic performance. The ultimate goal of scientific research in EGS is the development of a technology to produce electricity and/or heat from the internal heat of the Earth in an economically viable manner, independent of site conditions.

Research and Development Challenges:

From the current state-of-the-art, priorities covering four main research areas have been defined in the medium (by 2020) to long term research perspective (beyond 2020)[3]:

- Exploration and investigation to identify closely the nature of geothermal heat concentrations and prospective reservoirs at depth, also improving methods to predict reservoir performance/lifetime;
- Improving drilling and completion technologies for geothermal wells;
- Reservoir engineering, stimulating the fluid flow underground;
- Improving the efficiency of the exploration activities needed to provide heat and/or electricity from wells. This includes e.g. the production pump, the piping, the heat exchanger, the power plant and any auxiliary equipment.

[3] For further data refer also to the findings of the ENGINE European project at http://engine.brgm.fr

6. Concentrating Solar Power

Background

The role and contribution of concentrating solar power technology in Europe will depend on four major factors:

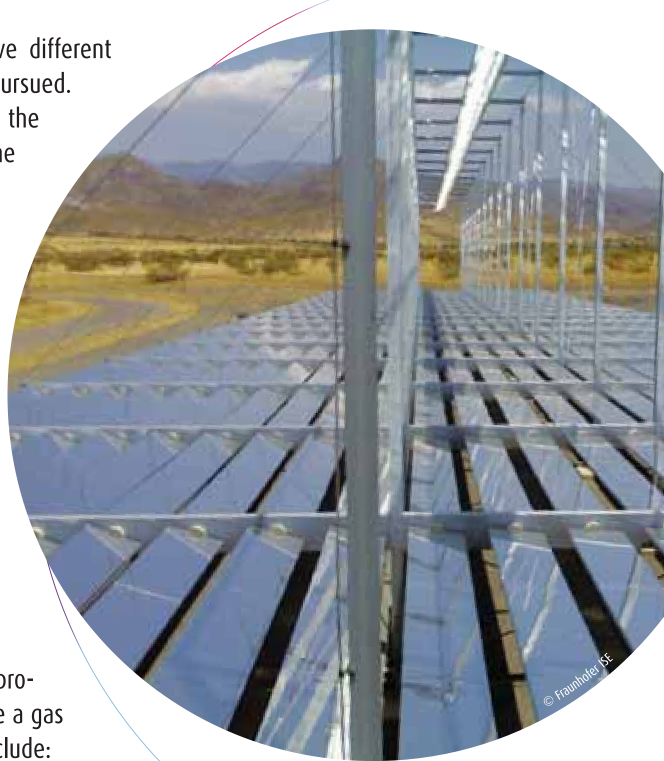
1. The capability to provide dispatchable bulk electricity with the same quality and reliability as conventional power plants, through the utilization of thermal storage and/or solar-fossil hybridisation concepts;
2. Further cost reduction through innovations, technology learning and scaling effects to compete in the bulk electricity market;
3. The possibility to provide, in some markets, not only electricity but also drinking water, heating/cooling and eventually solar fuels (long-term);
4. The availability of a European and Trans-Mediterranean high voltage DC grid that enables efficient electricity transfer from the sun-rich countries to the major users in the northern parts of Europe.

If the above targets are achieved, CSP cannot only replace significant conventional power plant capacities in Southern Europe, but it will also form the basis for integrating large shares of variable renewable electricity technologies, e.g. wind and photovoltaics, into the electricity supply, by compensating their fluctuating production in order to match the electricity demand profile. The additional costs to transport CSP electricity over longer distances via High Voltage DC lines, e.g. from the Mediterranean Region to Central Europe, will be more than compensated by the extensive solar resource in this area. Furthermore, this concept offers benefits with respect to European-North-African socio-economic relations. In particular, desalination and cooling could be an additional benefit essential for the development of the Middle East and North Africa (MENA) region.

CSP plants are centralized large scale facilities with very high initial investment for a single project. Several scaling steps are generally required before commercialization of new concepts is possible. Cost reduction may evolve through several technology development lines, for which the final step is the demonstration at 10-50 MW plant size with specific characteristics.

Research and Development Challenges:

Based on various research and development projects in Europe five different development lines have been identified which could be further pursued. Research and development targeted to achieve a demonstration at the 10–50 MW level would seem to be the highest priority for reaching the required technological and commercial targets.


© Fraunhofer ISE

The five proposed demonstration projects would be:

1. Demonstration of a 10-50MW CSP plant that generates and provides storage for high temperature (550°C) and high pressure turbine steam without using any intermediate heat transfer media. Research challenges include:
   - Components for higher temperature operation with alternative new heat transfer fluids (steam);
   - Innovative thermal energy storage using phase change materials;
   - Dispatchable operation concepts, e.g. based on weather forecasts.
2. Demonstration of a 10-50MW CSP plant that generates and provides storage for high temperature gas (up to 800°C) to operate a gas turbine without need for cooling water. Research challenges include:
   - Advanced heliostat design and tracking concepts;
   - Innovative receiver concepts for high temperature power cycles;
   - Innovative thermal energy storage;
   - Optimization of power cycle components (turbines) for solar application.

3. Demonstration of a 10-50MW CSP plant that uses novel heat transfer and storage media that are environmentally benign, increase operating temperatures beyond 500°C and reduce generation costs. Research challenges include:

- Components for higher temperature operation with alternative new heat transfer fluids (salt, gas);
- Innovative thermal energy storage concepts;
- Dispatchable operation concepts, e.g. based on weather forecasts.

4. Demonstration of combined solar electricity production and desalination in a 10-50MW plant with novel technologies, e.g. Linear Fresnel. Research challenges include:

- Proof of new concentrator concepts;
- Advanced reflector and absorber concepts;
- Innovative thermal energy storage.

5. Demonstration of solar fuel upgrading at commercial scale, e.g. steam reforming. Research challenges include:

- Innovative receiver reactor concepts for solar chemical application;
- Hybridisation concepts;
- Advanced process control.

In addition the following cross-cutting aspects need to be addressed:

- New reflector and absorber materials;
- Life time expectations and degradation mechanisms of components;
- Dispatchable operation concepts;
- Pre-normative research to address the lack of standardization.

7. Marine Energy

Background

In recent years the development of marine energy technology has progressed rapidly to the point where prototype systems have been installed and are now operational. It seems clear that these developments represent the dawn of a new industry focussed on the exploitation of the huge, clean energy resources available from waves and marine currents. Following the thorough testing and proof of the prototype systems, considerable challenges will remain to be tackled in order to move the technology towards commercial viability and provide the confidence required to attract project developers and investors.

An important component of the development of confidence in the technology is to ensure that the designers, manufacturers and project developers are equipped with design tools which are reliable, robust and safe without being unduly conservative. Certification and due-diligence review of marine energy devices will inevitably be required as part of the confidence building process and these will demand validated design analysis. It is only by making use of such reliable analysis supported by appropriate design codes and standards that the industry will be able to bring this new technology to market.

Scaling-up the Manufacture of Devices

The majority of devices currently under investigation exist either as theoretical models or have been built only at wave tank-scale or as reduced-scale prototypes. Research is required to see whether small scale devices can be scaled up successfully to full-size machines, maintaining efficiency and reliability.

Transport of the device to the site where it is to be deployed and installation including foundations, mooring, and water-tight sealants, needs to be considered. The costs of transporting devices are significant and greater public support should be provided for recovering these costs.

Research and Development Challenges:

- Testing, where advances are needed in the science of performance measurement and in solving device-scaling problems;
- Standards and certification leading to the establishment of robust guidelines for the design, development and evaluation of marine renewables.

Tidal

Although the tidal energy resource is large much of it is concentrated in relatively small areas around headlands and in channels formed between islands. In order to make the most effective use of the resource it will therefore be critical to understand the nature of the flow and how it is modified by the presence of energy extracting devices.

Research challenges:

- To downscale marine current resource atlases and to model water flow in channels and headlands, including the application of CFD;
- To test and develop new marine current devices;
- To model and measure the response of marine current devices in the presence of water flow.


© OceanPowerDelivery Ltd.

Wave

Wave energy devices must be designed to withstand a very large range of energetic waves. Engineering devices which are optimised for the mean wave climate but which are also capable of withstanding extreme waves with energy densities two orders of magnitude higher than the mean is of paramount importance.

The development of monitoring systems will be an important element in designing wave energy systems to withstand extremes.

Research and Development Challenges:

- The development of wave energy forecasting systems: better forecasting will not just add value to the electricity produced from the marine energy installations, but will help with the scheduling of maintenance and repair and enable better assessments to be made of the need to protect the device if severe weather is coming.

R&D efforts should be focused both on single device concepts and also on arrays of systems (wave farms) including:

- Research topics at single device level: advanced control techniques could be also considered to optimise performance and reliability;
- Research topics at wave farm level:
  - Wave climate forecasting (short, medium and long time scales);
  - Wave propagation (including interaction between devices);
  - Submarine electrical connection systems;
  - Transmission cables, AC or DC transmission.

VISION BOX: A LOOK BEYOND 2020

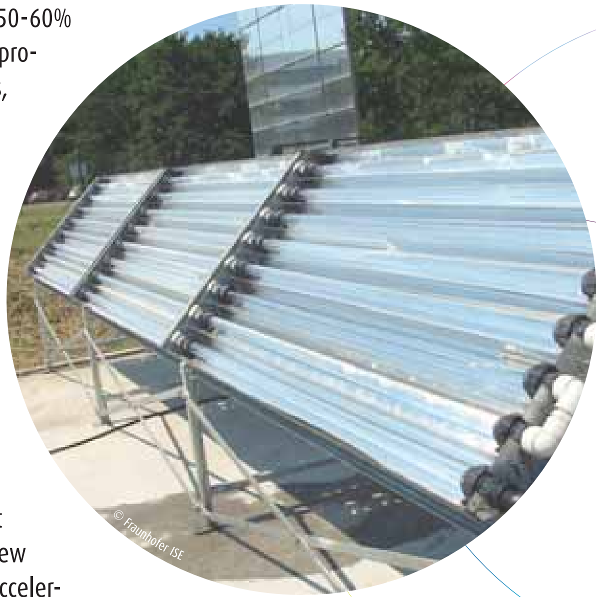
The contribution of some RETs would become more important after 2020:

- **Geothermal Energy:** development of systems for the exploitation of supercritical geothermal fields (temperature up to 500°C) at relatively shallow depths (< 4 Km)
- **Concentrating Solar Power:** focus on improvig steam reforming methods, leading to upgrade solar fuel at commercial scale. In the longer term, the possibility to provide, in some markets, not only electricity, but also drinking water, heating/cooling and, eventually, solar-based fuels should also play a fundamental role to enable the use of this RET.

- **High Temperature Superconductors** would play an important role in enabling a large integration of renewable energy into the grid. HTS devices would improve reliability of key components for renewable electricity production, while reducing their costs. HTS cables would contribute to reducing transmission losses and to increasing the capacity of electricity transmission. Energy Storage Systems, based on HTS materials, would enable a better integration of renewable electricity into the grid.
- **Wave Energy** devices will become commercially viable and sufficiently well-engineered to provide an appreciable fraction of Europe's electricity requirements particularly further offshore.
- **Solar Photovoltaic:** modules are becoming available producing electricity below the price of conventional power plants. The application of this technology is expected to increase enormously between 2020 and 2050
- By 2030 **wind energy** will be a reliable and cost-competitive energy source, thanks to further significant improvements in the whole wind power system. After 2020 **offshore technology** is expected to increase its contribution through technical and performance improvements.

HEATING AND COOLING FROM RENEWABLE ENERGY SOURCES

A. INTRODUCTION



The supply of heat for domestic and industrial purposes currently composes 50-60% of the final energy usage in Europe. The vast majority of this energy is provided by the combustion of fossil fuels such as oil, gas and coal. Cooling is, with few exceptions, realised by processes which are driven by electricity, which in turn is produced mainly from fossil fuels. For these reasons, all energy scenarios insist in a very substantial contribution of the heating and cooling sector towards the achievement of resource and climate protection targets.

Efficiency gains are required in all energy-related applications, but the heating and cooling sector provides a particularly high potential. The average quality of thermal insulation of the present building stock in Europe is far behind existing building standards, and even these do not represent the state-of-the art or even the most overall cost-effective solutions. Estimates, e.g. for Germany, already indicate a potential reduction of heating fuel consumption and hence CO_2 emissions to 30% of the present values if existing buildings were brought to the standards required for new buildings. Government regulations and market incentives are required to accelerate the upgrading of existing buildings, which are otherwise replaced at a rate of less than 2-3% per year. District heating and cooling networks, which are already quite common in a few EU Member States, must be installed on a much broader basis to make use of industrial waste heat and of the efficiency of larger, centralised installations.

In addition to domestic heating requirements, industrial process heat in the range of 100-1000°C consumes significant resources. Combined decentralised electricity production and use of waste heat is an obvious example, but more intelligent cascading of users at different temperature levels, e.g. by using heat pump technology, and more efficient heat exchanger technologies for heat recovery are required as well.

However, efficient use of thermal energy alone will not be enough to reach the objectives stated in the recently approved EU Directive on the promotion of the use of renewable energy sources. By setting an overarching target of at least a 20% share of energy from renewable sources in the Community's gross final energy consumption by 2020, the Directive establishes a strong legal framework also for the promotion of heating and cooling from renewable sources.

For instance, the new legislation (art. 13) requires EU Member States to "introduce in their building regulations and codes appropriate measures in order to increase the share of all kinds of energy from renewable sources in the building sector". The same article also includes a specific provision to promote the use of renewable energy heating and cooling systems and equipment "that [will] achieve a significant reduction of energy consumption".

The measures necessary at national level for the implementation of this Directive will be numerous and sometimes will imply significant upfront investments. However, the new legislation provides a stable policy framework and creates investors confidence –what is needed by the European renewable energy industry.

After an outlook at the technologies already available for heating and cooling from RES, the sections that follow in this chapter will look at which research and development challenges still lay ahead if the EU is to achieve its ambitious targets by 2020.

B. TECHNOLOGIES AVAILABLE FOR HEATING AND COOLING

1. Building Technologies

Appropriate building technologies are a pre-requisite for reduced energy consumption of buildings and a high share of renewable energies for heating, cooling and lighting. At the same time, the comfort of their inhabitants needs to be maintained or even improved. Technologies available for energy efficient buildings are represented below:

ENERGY-EFFICIENT BUILDING

LOW EXTERNAL HEATING DEMAND	PASSIVE COOLING	ADVANCED LIGHTING	ENERGY SUPPLY SYSTEM
compact building design	low load design	daylight design	solar thermal collectors
solar gain utilization	utilization of thermal mass	advanced glazing	solar cells
improved insulation	night ventilation	advanced shading	heat pumps
ventilation heat recovery	slab cooling	efficient artificial lighting	district heating
ground heat exchanger	ground heat exchanger	automatic lighting controls	solar assisted sorptive cooling
appropriate siting and orientation	evaporative cooling	...	fuel cells
...	...		...

INTEGRATED PLANNING AND SIMULATION

Source: EUREC Agency, FP7 Research Priorities for the Renewable Energy Sector (2005)

The following roadmap for the external primary energy demand for heating, cooling, lighting or other building services is recommended:

- By 2010 new residential buildings in the EU should need no more than 60 kWh/m²/year. New office buildings should need no more than 100 kWh/m²/year, which is also the target for retro-fitted residential buildings.
- By 2020, energy demand for 40% of all buildings in the EU should be below 100 kWh/m²/year. This also implies an ambitious retro-fitting rate for the existing building stock. The standard for new residential buildings in 2020 should be 45 kWh/m²/year.
- By 2050, new buildings in the EU should not use more than 30 kWh/m²/year. At the same time, 50% of the existing building stock should reach values below 60 kWh/m²/year.

Opportunities arise particularly in the design of new buildings to closely integrate considerations of architecture and energy efficiency with a high degree of cost-effectiveness. Innovative products, technologies and systems should find application in future European buildings, in order to comply with the always increasing market and legal standards.

The use of more or less sophisticated engineering systems to heat, cool and light the interior to ensure satisfactory indoor conditions for the occupants is most often the approach in modern buildings. Such systems are naturally energy consuming and are usually considered add-on equipment to the building envelope. It is certainly valuable to ensure that heat losses from the building fabric and its heating services are reduced through insulation, but the starting point needs to be somewhat different. An alternative approach integrates consideration of the occupants, their living and recreation and working places, and the outdoor environment in an architecture which seeks to utilise ambient energy sources and seasonal and diurnal outdoor changes to reduce reliance on mechanical and electrical systems. This approach is characterised by the use of building elements such as walls, windows and floors, for heating, cooling and lighting. The purpose is to deliver usable energy and thus provide comfortable conditions in the occupied parts of the building at the times of the year and the day when heat is required, without causing overheating. Optimal use of daylight is of considerable importance in non-domestic buildings.

Ventilation systems, in particular air-conditioning, consume significant energy during usage and need regular maintenance to prevent growth of micro-organisms which can health damaging. Design strategies should seek to minimize the need for air conditioning in the first instance, and management strategies should ensure that where such systems are installed they are properly maintained

Bioclimatic or passive solar design now represents one of the most important strategies for the replacement of conventional fossil fuels and reduction of environmental pollution in the building sector. Depending on the predominant need for heating or cooling, a wide range of passive technologies are now available to the building designer for new and retrofit building projects. At little or no extra cost compared with conventional construction, this can result in buildings which make use of renewable energies, and which are both more energy-efficient and offer higher standards of visual and thermal comfort to the occupants.

2. Bioenergy

Biomass is the main contributor from renewable energy sources. In Europe, it counts for two thirds of renewable energies and 4% of total energy. For heating purposes, biomass is mainly used in individual installations, i.e. in open fire places with poor efficiency and significant dust and toxic gas emissions, and much more effectively in modern pellet or wood burners. A large potential exists for the use of solid biomass in larger central heating plants (potentially in conjunction with electricity generation) in combination with district heating networks. In this case environmental problems, like the particulate matter emissions or fumes, could also be efficiently solved. The operation of biomass-fired co-generation plants may be extended if waste heat is utilised in a chiller for district cooling purposes during the summer.

Figure 3: Cost of biomass for heating purposes (BMU 2004a)

The main determinants for the economic assessment of biomass application for heating are the costs of the raw material. This cost ranges widely from "negative" costs of waste materials, over relatively moderate costs for rest materials and all the way to the fairly expensive energy crops. Accordingly, there is also a broad spectrum of energy provision costs, as shown in Figure 3. Even more efficient solutions may be possible through gasification of solid biomass, but this technology is still under development and therefore comparatively expensive. When considering the most sustainable use of biomass, rest/waste materials should preferably be considered.

3. Solar Thermal Energy

Solar thermal energy has a huge potential for the heating of water and buildings, but currently contributes less than 0.1% to the total heat requirements. The latest projections suggest an annual growth rate of approximately 18% in the period 2006-2010, up to 1.5Mtoe of installed capacity in 2010. The same estimations indicate a target of 12 Mtoe in 2020. In the long term solar thermal energy is likely to contribute to renewable heat consumption with some 80 to 90 Mtoe. Solar thermal collectors are a mature and reliable technology. So-called solar combi-systems, which provide solar thermal energy for water and space heating, increasingly enter the market. Such systems typically achieve an overall solar fraction of 20-30%. Large solar systems, sometimes with seasonal heat storage, can achieve higher solar fractions, but currently at higher costs. To achieve the solar contribution outlined in numerous prominent scenarios, solar-supported district heat systems with large heat storage facilities will have to be installed at an accelerated rate.

The use of solar heat to fuel industrial processes, such as in the food, petrochemicals or minerals processing industries, is still in its infancy, even though there is a huge potential particularly in the temperature range up to 250°C. In this range, the process heat demand in the EU represents about 300 TWh/year, which is about 8% of the total final energy demand. High performance flat plate collectors or vacuum tube collectors can be used effectively up to 120°C. For higher temperatures, concentrating collectors of parabolic trough or Fresnel type must be used.

Solar thermal cooling systems have become of significant interest, due to the increasing need for building air-conditioning and the advantage of synchronous cooling demand and solar radiation conditions. A significant number of pilot installations are in operation, mainly for larger buildings. Smaller solar cooling systems for 1-2 family houses or small office buildings are under development in several institutions, but will require the development of high performance collectors.

With regard to any solar thermal application, heat stores are a key element since they compensate the time-lag between the available solar energy and the required heat demand. Storage periods are in the range from a few hours up to several months.

4. Geothermal Energy

Geothermal energy has been exploited for heating and cooling for a long time. It has the potential to supply a significant share of the European demand for heating and cooling, particularly due to its non-fluctuating availability. Some of this energy will be provided from the waste heat of geothermal power plants via district or distance heating networks, while the majority will originate from shallower sources in local or district environments. In addition to space heating/cooling, industrial and agricultural applications can be foreseen.

In 2007 a total of approximately 2.5 Mtoe has been supplied by geothermal heating within EU27, and more than 1 Mtoe in other European countries. Predictions for the installed thermal capacity (including geothermal heat pumps) amount to ca. 10,000 MWth in 2010 and 40,000 MWth in 2020 and 80,000 MWth in 2030 (EGEC 2008).

Typical costs are as follows:

HEATING & COOLING		Costs 2005 Range (€/GJ)	Average (€/GJ)	Cost reduction by 2030 (% 2005 costs)
Deep geothermal		0,5 to 11	2	+11
Shallow	Heat only	3 to 89	19	-9
	H&C: Heating	2 to 75	17	-8
	H&C: Cooling	2 to 97	16	-8

Source: EGEC (2008)

Today geothermal energy is used directly only at a few sites in Europe, e.g. Iceland, where steam or hot water directly from geothermal wells or from the condenser of geothermal power plants is fed into a district heating system.

More common and currently experiencing some sort of renaissance are geothermal heat pump systems, which extract low temperature thermal energy from the environment and upgrade it efficiently using electricity and sometimes natural gas driven thermodynamic cycles. Various well-established technologies are on the market, the selection depends on the available heat source (i.e. air, ground water, underground) and the heating technology of the building. Vapour compression and adsorption cycles may be used for heat pumps. In general, ground source heat pump systems are significantly more effective than air-based systems, but may require larger investment. Heat pumps may be operated, if possible, as single source of thermal energy (monovalent) or in conjunction with other renewable or fossil techniques (bivalent). Combined systems based on reversible heat pump operation may be used for heating in winter and cooling in summer. Typical installation costs for single-family houses in Europe are in the order of 7500-15000 €, specific heat costs are from 6-10 Cent/kWh.

5. Electrical Heating

Electrical heating using electricity generated from renewable sources may be an attractive long term option; from an exergetic point of view, however, most other uses of electricity should be preferred.

C. POTENTIAL OF RENEWABLE ENERGY FOR HEATING AND COOLING IN EUROPE

The potential of renewable energies for heating/cooling in Europe is huge. Biomass, solar energy and geothermal energy sources for heating and cooling are estimated to yield up to 240 EJ/a, which is ten times the current annual heat demand in Europe. Even when taking into account the competition for biomass for producing electricity or biofuels, and structural constraints limiting the use of geothermal energy, there is no lack of renewable energy to satisfy European heating and cooling demand. However, the lacking availability of district heating networks is a severe structural barrier to the large scale utilisation of geothermal and solar thermal energy. Figure 4 shows that the exploitation of energy efficiency measures in Europe can decrease the current demand for heating and cooling by 40%. It is expected that by 2050 solar, biomass and geothermal energy cover half of the remaining demand.

Figure 4: Development of the heating/cooling supply structure in OECD Europe in a 2°C Climate Protection Scenario (Krewitt et al 2007).

D. R&D REQUIREMENTS FOR HEATING AND COOLING

To achieve the ambitious targets for climate and resource protection, substantial R&D activities are required. They include the development of individual technologies for utilizing renewable energies, but also the improvement of existing, conventional technologies, the development of new building materials, house energy management concepts, lighting, planning tools and so on. An overview of research requirements on heating and cooling from renewable energies will be outlined in the following paragraphs. This also includes appropriate building concepts taking into consideration not only reduced thermal losses but also the specific requirements of renewable energy technologies, such as thermal storage or the increasing effectiveness with reduced temperature of the heat transfer medium (i.e. water or air). All R&D activities must be accompanied and supported by detailed life cycle assessment of the environmental effects of the various technologies as well as scenarios for the commercial and wide-spread implementation.

1. Innovative Building Concepts

Specific needs linked to the building market are the optimal use of the limited building shell area. This calls for combining structural demands in building components with for instance solar functions or heat storage and thin highly efficient insulation layers, like opaque vacuum insulation panels and evacuated glazings. Phase change materials are a promising option for short and medium term storage. Integration of this storage type into the building construction, e.g. into the wall structure of buildings is of particular interest for lightweight constructions.

Solar collectors which become part of the building shell have to be developed. These collectors may combine several functions. They can become part of the transparent side of facades and have daylighting and shading functions as well as energy gaining functions. Collectors that are part of the opaque façade have heat protecting functions and are used for energy gains. In addition they may function as storage and/or heat supply system on the internal part of the wall.

Measures to optimize energy gains of façade integrated collectors are needed such as total or partly tilted absorber components. Basic research in this field mainly has to cover material issues and is closely linked to applied research on the component development level. Following an extensive development, testing and demonstration phase, these technologies need to be standardized and modular designs be developed.

Control systems are required in order to operate the entire building energy management system. Typically the control system consists of a microprocessor-based controller, sensors for the detection of input parameters (e.g. temperatures, radiation) and actuators such as pumps and valves. Advanced control equipment must be developed which is self-adapting and self-optimising. Modern control tools (such as Fuzzy Logic, Neural Networks, Expert Knowledge) must be adapted to building applications, allowing weather forecast based system control for optimised user comfort and energy efficiency. Standardised methods for the assessment of the overall performance of the system/building and for checking if the requirements of the energy label are fulfilled will be required. The newly developed centralised control systems for new and existing building concepts need to be tested and demonstrated under relevant conditions and then converted into commercial and customer-friendly products.

2. Bioenergy

The efficiency of thermal, physical and biochemical conversion processes of biomass cannot be assessed independently from the subsequent processing and combustion of the resulting secondary energy vectors. In the following, these steps will be considered together in the relevant paragraphs. Solid biomass has for a long time been used directly for the generation of heat. Hence, this option will be considered as well in the following listing of research requirements (Kaltschmitt 2008).

Moreover, additional research topics may include the combination of biomass with other renewables technologies, such as biomass fuelled co-generation plants that use the condensation heat for district heating or cooling by absorption heat pumps. This extends the biomass power production as otherwise co-generation plants are normally shut down during summer.

Thermo-chemical Conversion

Direct combustion requires improvements in combustion efficiency (e.g. condensing boilers), spectrum of fuels, reduction of dust emissions, development of small systems and the development of efficient heat/power generation systems in the kW range.

To improve the efficiency of gasification technology, a number of issues should be addressed, such as the development of smaller units for decentralised combined heat and power, improved reliability of integrated gas cleaning systems, optimization of product yield and quality and concepts for biomass combined heat and power plants.

There is also a need for further development of pyrolysis processes, to improve the efficiency, product quality and the further processing of the resulting pyrolysis oil.

Physico-chemical Conversion

Alternative processes involving the extraction of secondary energy carriers from biomass or the chemical conversion of various components need to be investigated, as well as the utilisation of the resulting products for direct combustion or in the production of liquid fuels.

Bio-chemical Conversion

The production of alcohols from biomass is a well-established process. Nevertheless, significant research is required to increase the conversion efficiency to an extent where these fuels can make a significant contribution to the overall energy economy. This includes the microbiology and the process engineering of the biomass conversion, the available resource base, the utilization of by-products, and the development of integrated bio-refinery concepts.

The production of biogas must be improved by better disintegration of the raw materials, development of efficient and stable bacteria for difficult biomass types, increased process technology for higher yield, and reduced environmental impact.

3. Solar Thermal Energy

The following R&D priorities for the field of solar heating and cooling are an extract of the Strategic Research Agenda produced by the European Solar Thermal Technology Platform, ESTTP[4]. Basic and applied research requirements have been identified for the key components and for the complete systems. The resulting developments need to be tested and demonstrated in relevant sizes and numbers to prove the robustness of technical components, systems and control schemes, and to assess their long-term performance. Finally, there is a need for standards and certification.


© Bundesverband So

Solar Thermal Collectors

Current collectors are reliable and relatively effective. However, they do not fulfil future demands at low irradiance or high temperatures. Fundamental research requirements are mainly in the area of materials development, such as functional surfaces, improved selective absorbers, better mirrors, cheaper glass with high solar transmittance, glazings with switchable optical properties, and heat transfer fluids with higher temperature stability and improved thermal insulation. Depending on the development of raw material prices, substitution materials may need to be developed.

Development activities are necessary to reduce the prices below what is possible by mass production alone. This includes the integration of conventional solutions in building facades and roofs, new materials and joint development of envelope components that contain both the collectors and the façade or roof. Furthermore, improved sensors for control purposes and new testing procedures including accelerated ageing tests of solar system collectors and components and tests for specific applications such as façade collectors or maritime installations are required.

Thermally Driven Cooling and Refrigeration

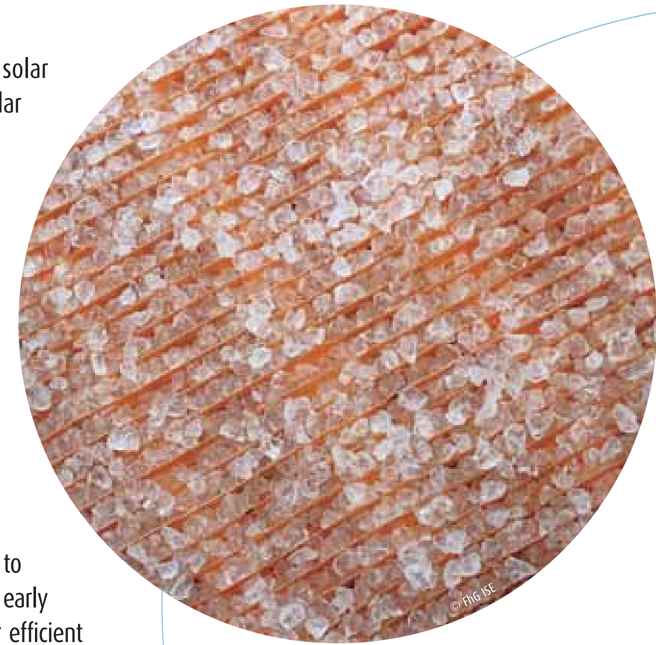
Processes to generate cold from heat are essential for solar thermal cooling and air-conditioning systems. Basic research is needed to optimize thermally driven cooling cycles, which achieve higher values for the coefficient of performance (COP), are more compact and can operate at lower driving temperatures compared to today's technology. This includes material research on new sorption materials, new coatings of sorption materials on heat exchanger surfaces, new heat and mass transfer concepts and design of new thermodynamic cycles. Other components where basic research is needed include compact cold storage using phase change materials or thermo-chemical reactions, the development of new highly porous sorption materials and the development of sorptive materials (nano) coatings on different metal substrates for optimized heat and mass transfer.

Once the fundamental components are developed, new equipment will have to be designed and tested, which will also require the development of new, standardised test methods for solar thermally driven cooling cycles. An important aspect will be size, noise and cost reduction to allow implementation of such systems into the domestic environment.

[4] More information is available at www.esttp.org

Solar District Heating and Cooling

Large-scale solar heating (and cooling) systems are here defined as solar heating (and cooling) systems with more than 500 m² of (glazed) solar collectors (i.e. > 350 kWth nominal thermal power). In addition to specific materials developments for underground seasonal heat stores and control of the complex solar system, demonstration of different concepts for solar district heating and cooling systems in a number of typical EU member states is required based on feasibility studies for regional requirements, geotechnical conditions and building standards.



Solar Systems for Water Treatment and Desalination

Solar driven, decentralized water treatment systems (e.g. sea water desalination) providing fresh drinking water of high quality to isolated customers like single households, small to medium size communities, remote hotels or tourist resorts can make a substantial contribution to sustainable development. This application of solar energy is still in the early stages of development requiring R&D on new/innovative materials for efficient thermally driven heat and mass transfer (evaporation and condensation). Functional polymer foils and fabrics with good thermal conductivity are required to reach sufficiently high recovery rates at moderate cost. Considering the typical future installations, robust concepts and easy technology transfer must be a main target.

New solar collectors and heat storages must be developed for the specific requirements of solar desalination systems, such as elevated temperature range (90-150°C) and resistibility against the aggressive atmosphere at the sea side.

Solar Heat for Industrial Processes

The following research and development activities are needed to develop the required equipment and the technology enabling a wide-spread application of solar heat in industrial processes: cost-effective solar fluids, collector and storage materials suitable for elevated temperatures up to 250°C, development or adaptation of existing collector types for elevated temperatures, innovative heat storage concepts for elevated temperatures, integration of solar heat in existing industrial processes, mathematical models and software tools to design solar assisted processes, development of system optimization methodologies to identify the best combination of solar integration and heat recovery.

Particularly in the area of solar process heat, successful installation and operation of a number of demonstration units in different processes will be necessary to convince industrial companies about the benefits of solar technology.

4. Geothermal Energy[5]

Two thirds of the costs of geothermal plants are associated with drilling the wells. Significant advances are possible in deep drilling technology, such as innovative drilling technology for exploration and preliminary reservoir assessment,drilling for reservoir development and exploitation, and use of supercritical CO_2 as fluid.

Exploration and identification of sites suitable for deep geothermal heating and cooling bores requires improved tools for resource mapping, a better understanding of techniques to prolong the lifetime of existing boreholes and the re-interpretation of existing geophysical, geological and geochemical data to identify patterns that suggest the presence of a good resource below ground. Numerical models of geothermal bores must be improved to better predict the bores' long-term behaviour. Tools for quantitative estimation of the risks (e.g. costs, capacity, environmental impact) associated with the use of geothermal energy should be developed.

For geothermal district heating, technology evolutions are needed for in site assessment techniques, and on the reinjection into difficult aquifers.

[5]The following research priorities are consistent with the highlights of a recent publication (2009) of the European Geothermal Energy Council (EGEC): Research Agenda for Geothermal Energy - Strategy 2008 to 2020.

Heat pumps are fairly established technology for upgrading thermal energy from the ambient air or from the underground at any depth down to 150 m or more. Nevertheless, further R&D efforts are required to utilise the potential of geothermal heat pump systems and to increase the use of shallow geothermal. In particular, future scientific research should focus on the improvement of the underground systems, with the aim to strengthen resistance and reliability hence minimizing the maintenance needs of these systems. It is also important to progress with the development of components which are easy to connect and disconnect from the surface, as the geothermal heat pump has key components underground.

Other priority areas for future research may include increased efficiency of the basic thermodynamic cycles, new environmentally benign refrigerants, innovative heat and cold storage concepts, the effective achievement of higher temperatures for installation in existing heating systems, the combination of heat pumps with other renewable energy sources, and the utilisation of thermal energy from waste water.

In short, by 2020 technology evolution in geothermal heating and cooling is expected to lead to an increase in the usable geothermal potential, to improve plants efficiency, and to decrease installation and operational costs – especially those related to drilling activities.

Storage of Thermal Energy

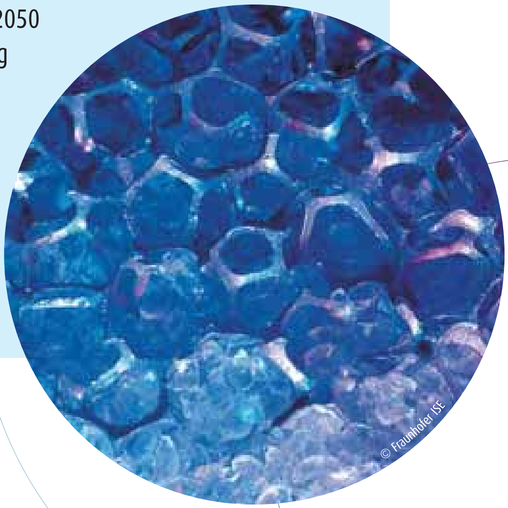
Improved thermal energy storage is essential for the more effective and widespread utilisation of several heating and cooling concepts using renewable energy carriers. This includes the obvious use of solar energy as well as combined heat-power provision with biomass or from geothermal power plants.

Basic research in new materials for thermal energy storage is essential in order to reach the required breakthrough in high energy density thermal storage. This will include improvement of existing thermal storage systems, like systems based on phase-change materials and based on sorption. In the longer term, thermo-chemical thermal storage systems need to be developed. This will require a better understanding of the relation between structure, composition and thermal storage characteristics of these materials.

Examples for detailed research topics are the development of macro- and micro-encapsulation techniques for phase change materials (PCMs), flexible volume tank systems, and reactors for thermo-chemical heat storage and for sorption thermal storage systems. Another interesting aspect is the demonstration of systems combining long-term thermal storage with short term thermal storage.

VISION BOX: A LOOK BEYOND 2020

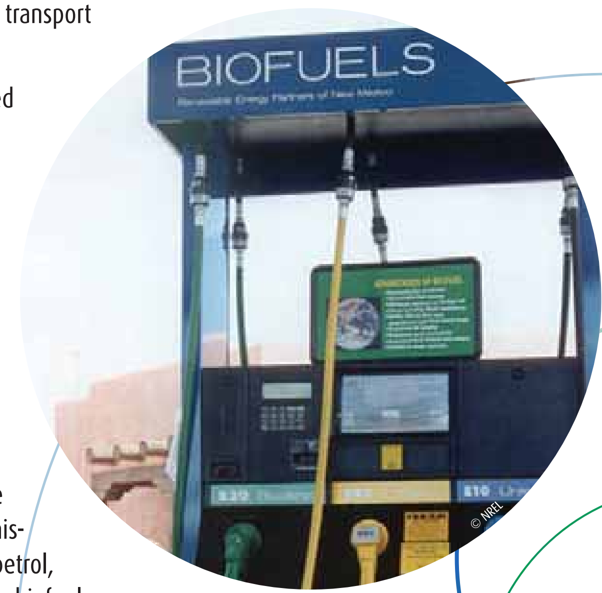
- **Solar thermal** energy has the potential to cover 50% of total European heat demand by 2030, under the condition that appropriate energy saving measures are implemented (so to achieve a 40% demand reduction compared to 2008 levels).
- **Innovative building technologies** have the potential to significantly reduce the energy consumption of new and existing buildings. Under the technology scenario foreseen by the ESTTP, by 2050 new buildings will consume less than 30 kWh/m^2/year while 50% of the existing building stock will reach values below 60 kWh/m^2/year. This could be achieved by reducing the external heating demand, through advanced lighting and by adapting energy supply systems. For this vision to become reality, an entire new concept of "active solar buildings" shall become a market standard, integrating renewable heating and cooling systems already at the design stage into new constructions.
- **Thermal storage** is a crucial technology for the further development of heating and cooling systems from RES. By 2030 a new generation of thermal energy stores is needed, allowing heat storage with a five fold energy density and on a seasonal timescale so that solar heat accumulated over the summer may be used during the winter months. Fundamental research in new materials is essential to achieve these ambitious objectives, aimed at developing new systems characterized for being compact, cost effective, safe and easy to handle.
- Improved thermo-chemical, physico-chemical and bio-chemical conversion processes for **biomass** may lead to a new generation of cheaper, cleaner and more efficient heating systems. By 2030 combined Heat and Power (CHP) cogeneration plants with further increased overall annual efficiency (over 90%) will allow dramatic savings in greenhouse gas emissions, already contributing more than 20% to the total European heat supply. By improvement of the gasification process for the second generation biomass, the application of large scale biomass gasification for the production of heat and power becomes available.
- The use of **geothermal energy** for heating is expected to increase 10-fold by 2050 compare to 2007 levels, to reach a cumulated installed thermal capacity (including geothermal heat pumps) of around 80.000 MWh in 2030. Already a top scientific research priority today, geothermal drilling technologies and techniques are even expected to keep improving beyond the 2020 timeline, to achieve a 25% reduction of the cost associated with these activities compared to current levels. Conservative estimations indicate that by 2030 the performance of heat pumps will be improved to the extent that the total cost of geothermal heat supply will decrease down to 54 €/MWh.



RENEWABLE ENERGY IN TRANSPORT APPLICATIONS

A. INTRODUCTION

A variety of technology options exist for using renewable primary energy in the transport sector, some applicable in the near term, some applicable in the longer term.



© NREL

The present, near-total dominance of Internal Combustion Engines (ICEs) fuelled with fossil fuels in the propulsion of road vehicles, and society's familiarity with and appreciation of the experience of driving using this technology and fuel, put a tight constraint on the options for using renewable energy in the transportation sector. The renewable energy must be delivered in the form of a fuel that is a) comparable in price to the fossil fuel it is substituting; b) energy-dense and easy to handle; and c) that meets agreed specifications.

Until combinations of technologies are available that can attract vehicle buyers away from the internal combustion engine in significant numbers – something that is not expected for the next one to two decades in Europe – biomass transformed into a form suitable for these engines will be the primary renewable energy resource used in road vehicles. A disadvantage of using the biomass resource for this purpose is that it can generally save more GHG emissions if it is used to substitute power production from coal than if it substitutes petrol, diesel or other fossil fuels used in vehicles[6]. For this reason, scientific research in biofuels production should maintain its primary focus up to 2020 on further GHG emission reduction whilst enhancing economic viability. Indeed, the recently adopted "Renewables Directive" requires new biofuel plants built after 2017 to manufacture fuels that save 60% of the lifecycle emissions of diesel or petrol.

Electric motors could end the dominance of ICEs. This is a well-understood technology not widely used in cars because of the difficulty in storing the electricity needed to power the motor. To remove this obstacle to the use of electricity as a fuel, battery technology will need to improve to the point where batteries can be charged safely from an external source, typically mains electricity, and keep a car running for a few tens of kilometres. The batteries will also have to be small and relatively inexpensive.

© ADEME

The greatest savings on fuel and the greatest benefit to the environment will come by first targeting electric motors and batteries at the small car mass market. This is because, for a given size of battery, a small car, often carrying light loads and travelling a few kilometres a day, will be able to run a greater proportion of its total daily mileage using electricity. They will therefore be able to avoid a greater proportion of their petrol or diesel consumption than heavier vehicles running greater distances between charges. Heavier vehicles and vehicles that travel long distances each day and that cannot be recharged during the day will continue to rely on biomass-derived fuel to increase their use of primary renewable energy sources.

Hydrogen can be produced from primary renewable energy sources, compressed or liquefied, and used in vehicles. When a region of the world is producing quantities of renewable electricity too great to be transmitted to consumers along power transmission lines, using the excess electricity to produce hydrogen could become a viable option. This is not expected on a large scale for several decades.

Hydrogen can also be produced from biomass and/or biological processes and used in transport applications, but, as indicated above for biofuels, this is in most cases not the use of the biomass that saves most GHG emissions. Another approach could be to create hydrogen thermo-chemically with concentrated sunlight.

The widespread use of fuel cells, oxidising hydrogen or (via a reformer) methane, is expected well after 2020.

[6] JRC 2008

B. RESEARCH PRIORITIES FOR THE USE OF RENEWABLE ELECTRICITY IN TRANSPORT

Charging electric vehicles from the grid, at present, is not carbon neutral, since the energy mix in Europe is largely composed by fossil fuels. Despite this, electric vehicles emit less CO_2 than petrol and diesel cars. This is mostly due to the fact that electrical engines and batteries are much more efficient than internal combustion engines. This implies that the higher the share of renewable electricity in the grid, the lower the emissions per car kilometre of vehicles charged from the grid[7].

A greater proportion of electrically powered vehicles would not only have environmental benefits, but also health benefits. By reducing the amount of respirable particles that are normally produced by internal combustion engines, the exposure to these particles of individuals living and working in urban environments would diminish, and as a result the overall health of the urban population would improve.

1. Improving Battery Technology

The roll-out of electric vehicles strongly depends on the improvement of battery technology, since the other components specific to electric vehicles, such as electric engines, are based on well understood technology with less scope for cost reduction.

The cost of batteries has so far prevented electric vehicles from being deployed on a large scale. Batteries with the most promising chemistry for electrically-driven vehicles, lithium ion, currently cost approximately 1000 €/kWh, but must become much cheaper if they are to store electricity for motive power in electric vehicles. In the long term, a cost of under 100 €/kWh is expected[8].

The main research priorities for increasing the use of battery technology are reported below:

- **Cost target.** The reduction in battery cost will in part be achieved with **cheaper electrode** materials. The current cathode materials are $LiFePO_4$ (lithium iron phosphate) and Li-Ni-Co-Mn-O (a combination of oxidised lithium, nickel, cobalt and manganese). Cobalt, an essential component of these electrode materials, is a scarce material and a replacement should be found.
- **Cell chemistry.** As previously underlined, the current cathode materials are $LiFePO_4$ (lithium iron phosphate) and Li-Ni-Co-Mn-O (a combination of oxidised lithium, nickel, cobalt and manganese). Batteries with these chemistries are capable of over 10.000 charge and discharge cycles with a loss of 15% of their initial capacity at optimal temperature conditions. However, the mechanism by which lithium ion cells age and deteriorate must be thoroughly understood.
- **Managing heat loss to ensure proper, durable and safe operation.** The costs that relate to limiting the build-up of heat in battery modules represent more than 10% of the module's overall cost. Regardless of its chemistry, the higher a battery's temperature, the shorter its lifetime (see figure 5). For optimal performance, lithium ion batteries should be kept at temperatures between 25 and 30°C. Their normal operating temperature range is between 5°C and 50°C. Temperatures higher than this range are not used as the life length of the battery is negatively impacted. At lower temperatures the power is limited due to the kinetics being slower.

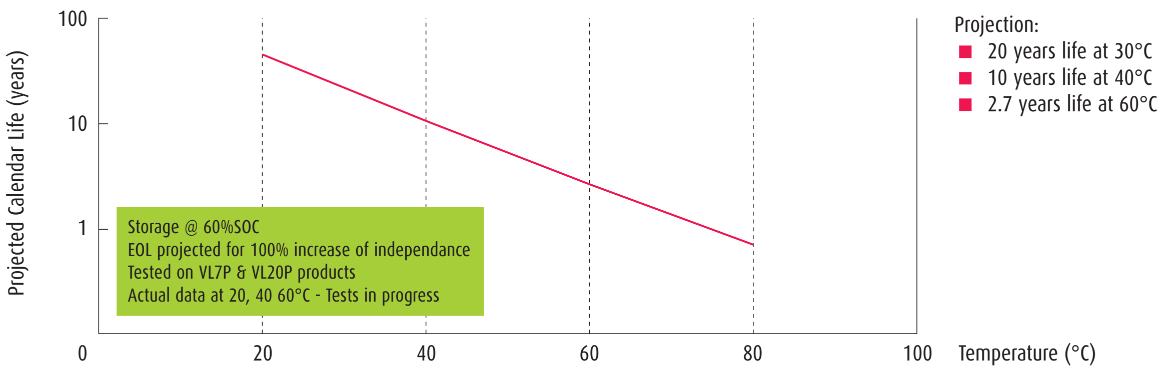
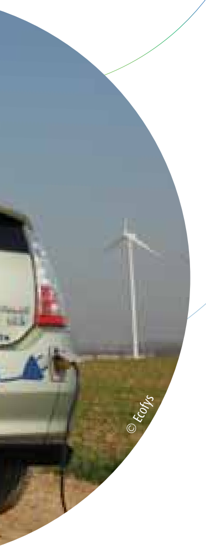


Figure 5: Cycle life expectancy of Li-ion batteries[9]

[7] For detailed R&D priorities on renewable electricity production, make reference to the previous chapter "Electricity Generation from Renewable Energy Sources"
[8] USABC (United States Advanced Battery Consortium)
[9] Jörg Kümpers (2008)


© Ecofys

- Disposal of the excess heat is therefore an important issue in battery R&D. It should also be possible to achieve an even temperature distribution without fans pumps or other active cooling devices.
- **Managing current flows and cell voltages during charge and discharge.** The management of current flows between cells and the voltage across cells is also important for safe battery operation. Not all cells have the same performance. In some configurations of series or parallel-connected cells, it is possible that a cell can be exposed to voltages above the safe limit because of a weak neighbouring cell that has a lower capacity at the same voltage. Malfunctions such as this can be detected by electricity management systems that, for example, measure voltages across different parts of the module. Additional research should, then, be addressed to designing better electricity management systems, as well as to searching for charging and discharging methods that cause less ageing in the cells and modules.
- **Standardized battery test procedures.** Batteries undergo a series of tests (e.g. overcharge tests, short circuit tests, thermal abuse tests, mechanical tests (crash, penetration, drop, immersion, shock) and performance tests) before being introduced in the vehicles. However, these tests are currently not standardised at industrial level. The introduction of standardised battery test procedures, globally recognised and accepted by the industry, is an important priority to enable general acceptance of battery technology.

2. Socio-economic Research Priorities

There is a need for dialogue between stakeholders, such as utility companies, consumers, and car manufacturers, in order to define a clear path to a widespread use and implementation of electric vehicles with high capacity batteries. The most problematic obstacle is the availability and organisation of charging points and similar infrastructure, and there are several visions in how to tackle this issue.

- It could be possible to have consumers exchange their batteries at charging stations in a more centralised vision, where it would also be possible to balance the grid by having a large amount of batteries connected to it. In this scenario the car owner would not own the battery.
- Another alternative is the more decentralised vision, where there would be plug-in docks wherever consumers would park, and the battery would charge while waiting. Charging times could vary from very short (fifteen minutes) to long time (up to eight hours).

Which alternative is most viable depends on the research advances regarding the cost, efficiency, the impact of heat on the life-length, and capacity of the battery, charging technology, the developments of smart grids, and the development of standards in the car manufacturing.

C. RESEARCH PRIORITIES FOR THE USE OF RENEWABLE HYDROGEN IN TRANSPORT

Hydrogen can be used either in a fuel cell (FC), which generates electricity and water vapour, or an internal combustion engine (ICE), which generates mechanical energy and water vapour. Transport powered by hydrogen does not produce any direct CO_2 emissions. The environmental impact of using hydrogen as transportation fuel depends on the source of the energy used to produce the hydrogen.

Significant technological advances have been made in recent years on hydrogen-fuelled vehicles. However, the feasibility of producing hydrogen in large quantities from renewable sources still requires much attention. The use of hydrogen in the transport sector is not hindered by problems linked to its production from renewable energies[10].


© DLR

[10] Refer to the chapter "Electricity Generation from Renewable Energy Sources"

1. Hydrogen from Concentrated Sunlight

High-temperature processes are one of the most promising options for large scale centralised hydrogen production from renewable resources because of the high efficiencies that are possible to achieve. A number of concepts are under development, mainly solar thermo-chemical cycles for water splitting based on metal oxides or sulphur, solar steam reforming of natural gas and solar-heated high temperature electrolysis. The main research priorities are presented according to the process.


© DLR

- **Solar thermo-chemical cycles.** For industrial implementation of solar thermo-chemical cycles, enhanced low cost metal oxide redox systems have to be developed. The receiver reactor technology must be scaled up to demonstrate the technology in the MW range on a solar tower from the 100 kW pilot plant scale currently demonstrated. The two available sulphur cycles use thermal splitting of sulphuric acid to produce hydrogen. The biggest challenge is material resistance to concentrated acids. Improved catalysts and component coatings at reasonable costs are needed. Electrolysis for the hybrid sulphur process needs also further improvements regarding higher current densities, lower overvoltages, reduced heat losses, and side reactions.
- **Solar thermal high temperature electrolysis.** Solid Oxide Electrolyser Cell Technology (SOEC) is still in an early development phase. SOEC works at higher temperatures than alkaline electrolysis, obtaining part of the energy needed through heat and therefore potentially yielding higher efficiency. Main challenges are the thermal and chemical long term stability of electrode materials and the stability of sealing. Significant increase of stack lifetime is essential for the realisation of commercial applications, as is the development of cost-competitive plant configurations using and integrating solar heat and renewable electricity. Solutions for the separation of hydrogen-steam-mixtures at high temperatures are required as well using membrane technologies or condensation and heat recovery.
- **Solar process incorporating carbonaceous resources.** Reforming carbon based fuels into hydrogen can reduce CO_2 emissions of at least 25%, than using them directly as fuels. These technologies are not carbon neutral unless bio-methane or other bio-derived resources are used.
  - **a. Solar steam reforming of methane.** Suitable materials for the receiver/catalyst have to be identified for achieving an optimised process.
  - **b. Solar methane cracking.** Solar methane cracking is performed at very high temperatures (more than 1200°C), decomposing methane into hydrogen and carbon. Research needs to be focused on materials that can handle temperatures above 1800°C.

2. Hydrogen from Biomass

Biomass can be gasified to produce syngas (a mixture of hydrogen and carbon monoxide), which is then used to make liquid fuels, such as ethanol, that are relatively convenient to transport and can be reacted with high temperature steam to produce hydrogen at or near the point of end-use.

In the coming years, research should focus on finding, or even engineering, specifically modified algae and cyanobacteria that directly convert water to hydrogen by biophotolysis (microbial production of hydrogen). Currently, these microbes consume some of the produced power in the form of H_2 (e.g., during N_2-fixation by cyanobacteria or phototrophic bacteria). Blocking or knocking out the H_2 uptake of the microbes would lead to a significant increase in the amounts of pure bioH_2. The US Department of Energy estimates a conversion efficiency of 6% to 10% depending on the type of bacteria. Research should be focused on improving the process efficiency. Alternatively, biological hydrogen production from biomass in dark fermentation process can yield high conversion efficiencies, particularly if the two processes (dark fermentation and photo-fermentation) are coupled. Dark fermentation is more efficient at elevated temperatures (50-80°C), where waste disposal can be combined with renewable hydrogen production.

D. RESEARCH PRIORITIES FOR THE USE OF BIOMASS IN TRANSPORT

Transport fuels derived from biomass feedstock (biofuels) can enable renewable energy to be used in transport without the need to substantially modify existing vehicles or the fuel distribution infrastructure. This makes them an attractive proposition when compared with options such as hydrogen fuelled vehicles, which may only be available in a more distant future, and require new distribution and transport infrastructures to be in place.

Biomass feedstocks are divided into two different categories: **"first generation"** feedstock and **"second generation"** feedstock.

"First generation" feedstocks are produced and harvested for their sugar, starch or oil content and are converted into "first generation" biofuel through different conversion technologies. "First generation" feedstocks include sugar cane or beets, corn, wheat, barley, rapeseed, soybeans, palm oil and jatropha. "First generation" biofuel production technologies convert only a part of the plant (its sugar, starch or oil content) into transport fuel, leading to inefficient production and developing issues such as competition between food and fuels and sustainable production for these feedstocks. Nowadays, the vast majority of biofuel production capacity in many parts of the world, except Scandinavia, is "first generation". Algae are also considered a "first generation" feedstock, but is considerably different than the others, since it is currently largely unexplored and holds a very promising theoretical potential.

"Second generation" feedstocks, also called "next-generation" feedstocks, will for the next 10 to 15 years be mostly composed of residue and waste cellulosic biomass, also simply called lignocellulosic biomass. "Second generation" feedstocks are generally produced as by-products in the agricultural and paper industry. "Second generation" feedstocks include wood residues from the logging industry, black liquor residue and discards from the pulp and paper industry; municipal solid waste such as wood, cardboard, paper, and waste fabrics; crop residues, such as stems and leaves from conventional food crop harvests; and energy crops, such as "short-rotation" woody crops, which includes eucalyptus trees, willow trees, and tall grasses (Worldwatch Institute, 2006).

Despite the fact that biofuel production is a well-known and proven technology, much research is still needed in order to reach the target, as stated in the RES Directive, according to which 10% of the total energy consumption for transport should be derived from renewable energy sources of any type, by 2020.

Research topics to enable the acceleration of the use of biomass in transport would cover both the cultivation of biomass and its conversion to a usable form of transport fuel (both in the liquid and gaseous status). The majority of these research topics have already been presented in the two previous chapters (Electricity and Heating and Cooling).

1. Cultivation of Biomass

In order to achieve the above-mentioned target for the biofuel sector, it is necessary to extend the area of land available for growing crops for biofuel production, while ensuring that enough land is available for growing food crops. Cultivation of non-food crops should also be in line with guidelines for environmental protection.

With this respect, research topics should concentrate on:

- Developing non-food crops which can be grown in areas where food crops cannot be cultivated, such as the shrub Jatropha, able to grow in semi-arid environments.
- Developing other plant species to bring marginal or contaminated land back into use
- Exploring other potential sources, such as animal fat and waste vegetable oil

- Fully developing biofuels from algae. Exploring and exploiting the potential of the sea surface, which could represent a great and untapped potential to provide combustible organic compounds (e.g. extensive colonies of farmed microalgae or phototrophic bacteria)
- Better understanding of the biomass resource and increasing crop yield (see info-box)

INFO-BOX: UNDERSTANDING THE BIOMASS RESOURCE

In recent years, the production and use of biofuels in transport applications have raised growing concerns on their impact on the environment, and on the potential trade-off in land use between food crops and non-food crops production. In this respect, more research focused on the need to understand the different types of biomass resources, their net energetic value, and their final impact on the environment is necessary to enable their growing use in the energy mix.

More precisely, the following topics should receive special attention:

- Investigate different types of biomass resources (including biowaste and energy plants), and their potential for supplying chemical energy to be used for conversion into transport fuels
- Define a clear methodology to estimate the energetic values of biomass resources. In particular, energetic values of agricultural byproducts and "waste" biomass (e.g. waste water sludge, manure, communal waste, food processing waste and other secondary high energy content materials) should be investigated, since they still represent the cheapest source of biomass for biofuels production
- Properly define "sustainability criteria" that enable an environmentally-friendly production of biofuels throughout the whole supply chain
- Develop a complex utilisation scheme of biomass for energy production, which combines various means of energy production from biomass with geographical conditions and local needs

2. Conversion of Biomass to a Usable Form of Liquid Transport Fuel

The strategy for this stage of the production chain is to ensure that the maximum possible proportion of the primary energy content of energy crops is converted into a valuable form, such as transport fuel.

"First generation" starches and sugars are converted into bioethanol through hydrolysis and fermentation. First generation oils are converted into biodiesel through transesterification. More on this subject and research priorities can be found in the publication chapter "Heating and Cooling from Renewable Energy Sources".

The production of "second generation" biofuels is a technology that is expected to expand dramatically. Production of biofuels from lignocellulosic feedstock currently poses a great difficulty since cellulosic biomass is naturally resistant to degradation. There are several ways to convert lignocellulosic biomass into liquid fuel. The two primary technologies are thermo-chemical conversion to produce biodiesel (gasification to create syngas followed by Fischer-Tropsch synthesis); and biochemical conversion to produce bioethanol, biogas or biohydrogen (enzymatic hydrolysis to degrade cellulose into sugars, followed by fermentation to convert into liquid or gaseous forms of fuel).

The main research priorities related to this topic include:

- **Pre-treatment.** The enzymatic decomposition of the polymeric material into its monomeric sugar components is an important part of the biofuel production process. This process is quite expensive, since enzyme cost adds up to about 25-30% of the total production cost in cellulose-based bioethanol production. While waste and residue lignocellulosic biomass can be found at low to negative costs, the process as a whole might still be uneconomic unless enzymes can be produced more cheaply. In order to reduce this cost, more R&D should be focused on **improving the use of other cheaper enzymes (e.g. pentose utilization pathways) for biofuel pre-treatment.** More R&D is also needed to **increase robustness and tolerance of these next generation enzymes to extreme environmental conditions.**

- **Minimise energy input for distillation.** About 40% of the bioethanol production cost is energy used for the distillation of the product. There are several ways to use locally available waste heat if such source is available at or near the production site (e.g., use of geothermal energy, solar collectors). The principle of combining various renewable energy production technologies should be further promoted and researched in order to reduce fossil fuel consumption for distillation. When for example the residual material from bioethanol fermentation is used for biogas production next to the bioethanol facility, up to 80% of the energy required for distillation of ethanol can be supplied from renewable biogas.

3. Conversion of Biomass to a Usable Form of Gaseous Transport Fuel

Anaerobic digestion enables production of biogas that can be combusted in a gas turbine to produce electricity (to be used in electric vehicles). Biomethane purified from biogas can be directly used as transportation fuel in natural gas propelled vehicles, primarily in public transportation. Bus fleets using biogas/biomethane are already running in several major European cities. Sweden has been the pioneer in testing this technology at large scale.

- **Anaerobic digestion for biogas production.** Anaerobic digestion of organic materials is a concerted action of several dozens of various microbes, which form a microbial food chain. Some of these microbes multiply within 20 minutes, others need several days to reproduce themselves. The population composition dynamically changes as the environmental conditions vary, but as long as anaerobic conditions are maintained the community produces biogas. In order to increase the efficiency of the biogas production process, research topics should be focused to gain an **increased understanding of the microbiological** events taking place in this complex multifarious community (e.g. proper mix of feedstock composition, pH, and operational temperature).
- **Anaerobic digestion to produce hydrogen.** Anaerobic digestion has a specific role for transport applications when the digestion process yields hydrogen instead of methane. Hydrogen produced by biotechnological means and biomethane can be used as fuel in fuel cells. In the short and medium term (up to 5 years from now) biohydrogen produced by fermentative bacteria may become a practically feasible technology. Bioconversion of organic compounds of biomass origin (energy plants, food production waste, agricultural and household waste, etc) via microbiological fermentation leading to bioH_2 production has been well studied and technologies are developed. However, research is still needed in order to **ensure that the combination of bioH_2 generation with waste disposal respects environmental protection considerations.**

VISION BOX: THE BIOREFINERY CONCEPT

Biorefineries are similar to petroleum refineries in concept: the feedstock (conventional or advanced) enters the refinery and is, through several processes, converted into a variety of products such as transportation fuels, chemicals, plastics, energy, food and feed. By producing multiple products, a biorefinery can take advantage of the differences in biomass components and intermediates and maximize the value derived from the biomass feedstock

A centralized facility to produce biofuels at an economical scale will cost hundreds of millions of euros and is likely still to be operating thirty years from now. These facilities should therefore be designed in a way that not only enables them to process the largest variety of different biomass feedstocks, but that also enables them to produce a range of high-value end products, depending on which market is most profitable at a moment in time.

Building this versatility into biofuel facilities (i.e. building "biorefineries") will reduce their dependence on the market for a single product or small number of products.

CONCLUSIONS

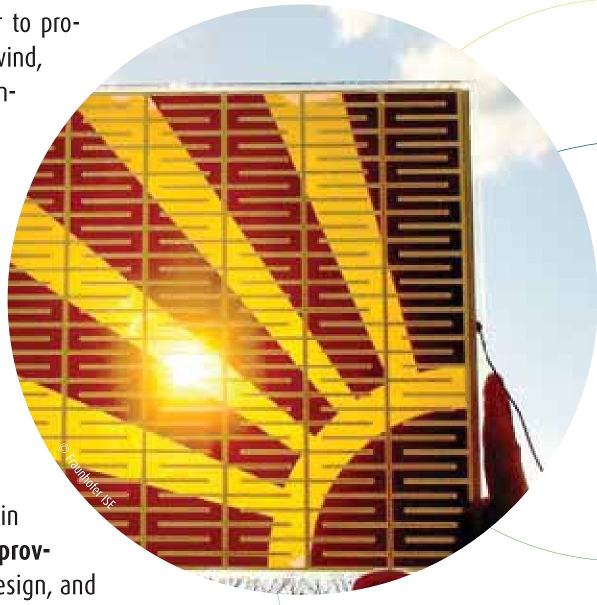
In 2008 the European Union adopted an historic legislative package on energy and climate change, which also includes measures to support the increase of the share of renewable energy sources in the total EU energy consumption.

The global downturn did not divert the ambitions of European policy makers to secure a new framework for the development and deployment of renewable energy technologies by 2020. However, it is clearly going to be a challenge to deliver rapid and sustained growth in renewable energy implementation in the current financial climate. At the time of writing, many governments both within in and outside the European Union appear to have recognised the opportunities for recovery offered by promoting the environmental sector, particularly related to energy.

This document provides support to current policies by addressing the research activities that are needed to underpin the growth of the renewable energy industry to achieve the 20% target by 2020, as set by the Renewable Energy Directive.

The three main chapters have discussed the research requirements by topic in relation to renewable energy for electricity generation, heating and cooling and transportation:

- Different technologies have been developed in order to produce electricity from renewable energy sources (wind, biomass, hydro, solar photovoltaic, geothermal, concentrating solar power, marine energy). These technologies are at a different stage of development, but all require some R&D with a view to **reducing their cost**, and **facilitate their integration into the grid** to increase their consumption.
- Biomass, solar thermal energy, and geothermal energy are current renewable energies used for heating and cooling in buildings, where technical research advances can be made (in e.g. conversion processes for bioenergy and improving geothermal drilling technologies). In order to increase the adoption of renewable energy technologies in buildings, research should also be addressed towards **improving building technologies**, including passive solar design, and energy efficiency.



- Different options are available for the production of renewable-based fuels for transport applications: **renewable electricity** to be used in electrical vehicles; **renewable hydrogen** to be used either in Internal Combustion Engines or in Fuel Cells (as a longer term option); **biofuels** (both in the liquid and gaseous status), which can be used with the existing infrastructure. In order to increase the use of renewable energy in transport applications, research is needed not only to improve the fuel production process (feedstock production and conversion into a usable fuel), but also to create the requested infrastructure for the uptake of renewable-based fuels.

Finally, some cross-cutting issues need to be tackled in order to enable a faster development of renewable energy technologies in all end-user sectors:

- **Research Infrastructures** (especially laboratory infrastructures): the approach to European funding of energy infrastructures should be extended to allow the integration of European experimental facilities in order to overcome fragmentation.
- There is a **lack of finance for demonstration activities** of new and improved renewable energy technologies. More demonstration is definitely necessary to bridge the gap between concept and implementation and a better financing scheme is needed.
- Especially in the heating and cooling sector **public funds** need to be increased in order to fulfil the required research. This sector contributes to about 40% of the overall energy demand in Europe but the utilisation of renewable technologies remains low at present.

- **Lack of qualified and skilled workers (engineers, installers, academics) in energy:** More efforts are essential in education. This includes not only specific studies for renewable energy as a course topic in itself, but more focus on renewable energy topics being included in electrical engineering, mechanical engineering, physics and other traditional technical studies. Post graduate studies, like the European Master in Renewable Energy offered by the EUREC Agency, are an essential education route, not only for young graduates but also to allow retraining to meet the rapidly growing need for skilled personnel in the renewable energy industry. Research training is also an excellent grounding for a career in this rapidly developing sector.

The expertise of the members of the EUREC Agency allows the whole renewable energy sector to be addressed and synergies identified. Whilst the document concentrates on research requirements in the renewable energy sector, it should be recognised that this is an essential component in the commercial development of the energy technologies that must form a large part of Europe's energy supply in the next two decades and beyond.

REFERENCES

BMU: The main features of the Act on granting priority to renewable energy sources (Renewable Energy Sources Act) of 21 July 2004 (http://www.erneuerbare-energien.de/files/english/renewable_energy/downloads/application/pdf/eeg_gesetz_merkmale_en.pdf)

Directive of the European Parliament and of the Council on the promotion of the use of energy form renewable sources amending and subsequently repealing Directive 2001/77/EC and 2003/30/EC (2009)

EGEC: Geothermal District Heating (2008)

EGEC: Research Agenda for Geothermal Energy – Strategy 2008 to 2020 (2009)

EUREC Agency: FP7 Research Priorities for the Renewable Energy Sector (2005)

Joint Research Centre: Biofuel in the European Context – Facts and Uncertainties (2008)

Jossen and Weydanz, Moderne Akkumulatoren richtig einsetzen: 1. Auflage ed. 2005, Leipheim, München: Reichardt Verlag. 283

Kaltschmitt et al: Renewable Energy – Technology, Economics and Environment (2008)

Krewitt et al: The 2°C scenario – A sustainable world energy perspective. Energy Policy 35 (2007) 4969-4980 (2007)

Kümpers: Advances in lithium and battery technology for hybrid electric vehicle. 1st International CTI Forum Alternative and Hybrid Drive Trains, Berlin (2008)

USABC (United States Advanced Battery Consortium): Goals for Advanced Batteries for EVs, http://www.uscar.org/commands/files_download.php?files_id=27

U.S. Department of Energy: Hydrogen Program, a prospectus for biological hydrogen production http://www1.eere.energy.gov/hydrogenandfuelcells/production/pdfs/photobiological.pdf

Worldwatch Institute: Biofuels for transport – Global potential and implication for sustainable energy and agriculture, Earthscan, London, UK (2006)

LIST OF ACRONYMS

AC: Alternating Current

CFD: Computational Fluid Dynamics

CHP: Combined Heat and Power

CSP: Concentrating Solar Power

DC: Direct Current

DSM: Demand Side Management

EGEC: European Geothermal Energy Council

EGS: Enhanced Geothermal Systems

EJ/a: Exajoule per year

ESHA: European Small Hydropower Association

ESTTP: European Solar Thermal Technology Platform

EU27: The 27 Member States of the European Union

FACTS: Flexible AC Transmission Systems

FC: Fuel Cell

FP7: Seventh Framework Programme for Research and Development

GHG: Green House Gas

GJ: Gigajoule

HTS: High Temperature Superconductor

HVDC: High Voltage Direct Current

ICE: Internal Combustion Engine

kWh: Kilowatt hour

kWth: Kilowatt thermal energy

MENA: Middle East and North Africa Region

Mtoe: Million tons of oil equivalences

MW: Megawatt

MWth: Megawatt thermal energy

PCM: Phase Change Material

PV: Photovoltaic

RES: Renewable Energy Sources

RET: Renewable Energy Technology

SET-Plan: Strategic Energy Technology Plan

SHP: Small Hydropower

SMES: Superconducting Magnetic Energy Storage

SOEC: Solid Oxide Electrolyser Cell

WAMS: Wide Area Monitoring Services

EUREC AGENCY MEMBERS

AEE-Institute for Sustainable Technology	Austria
ARMINES/MINES ParisTech	France
Arsenal Research	Austria
BRGM	France
CEA-INES	France
CENER	Spain
CIEMAT	Spain
CNRS-InESS	France
CNRS Laboratoire PROMES	France
CRES	Greece
CREST, Loughborough University	UK
DLR German Aerospace Centre	Germany
ECN	Netherlands
ECOFYS	Netherlands
EPFL	Switzerland
Fraunhofer ISE	Germany
Fundación CIRCE	Spain
FZJ Research Centre Jülich	Germany
Garrad Hassan & Partners Ltd.	UK
Helmholtz-Zentrum Berlin für Materialien und Energie	Germany
HUT Helsinki University of Technology	Finland
IEE-Institute for Electrical Engineering, University of Kassel	Germany
IMEC	Belgium
ISET	Germany
Institute for Solar Energy Research Hameln (ISFH)	Germany
IT Power Ltd	UK
ITER	Spain
European Commission, DG Joint Research Centre, Institute for Energy, Renewable Energy Unit	Italy
NaREC	UK
NPAC Northumbria University	UK
NTUA National Technical University of Athens	Greece
Carl von Ossietzky Universität Oldenburg	Germany
Warsaw University of Technology, Centre for Photovoltaics	Poland
STFC Rutherford Appleton Laboratory	UK
RISØ DTU	Denmark
TECNALIA ENERGIA	Spain
SFFE Senter for Fornybar Energi (Centre for Renewable Energy-NTNU-SINTEF-IFE)	Norway
UCD Dublin	Ireland
University of Athens	Greece
University of Szeged	Hungary
VTT	Finland
WIP-Renewable Energies	Germany
ZSW Centre for Solar Energy and Hydrogen Research	Germany

OTHER CONTRIBUTORS

Bavarian Center for Applied Energy Research	Germany
EGEC-European Geothermal Energy Council	Belgium
ESHA-European Small Hydropower Association	Belgium
University of Patras	Greece

SPECIAL THANKS TO

Nicola Pearsall from NPAC Northumbria University
Hans Müller-Steinhagen from DLR
Simon Watson from CREST
Kornel Kovacs from University of Szeged

European Commission
Research Priorities for Renewable Energy Technology by 2020 and Beyond

Luxembourg: Office for Official Publications of the European Communities
2009 — 44 pp. — 21 x 29.7 cm
ISBN 978-92-79-11948-4

How to obtain EU publications

Publications for sale:

- via EU Bookshop (http://bookshop.europa.eu);
- from your bookseller by quoting the title, publisher and/or ISBN number;
- by contacting one of our sales agents directly. You can obtain their contact details on the Internet (http://bookshop.europa.eu) or by sending a fax to +352 2929-42758.

Free publications:

- via EU Bookshop (http://bookshop.europa.eu);
- at the European Commission's representations or delegations. You can obtain their contact details on the Internet (http://ec.europa.eu) or by sending a fax to +352 2929-42758.

LB-78-096-76-EN-C

EURECAGENCY

European Renewable Energy Research Centres Agency

EUREC (EUROPEAN RENEWABLE ENERGY RESEARCH CENTRES) AGENCY

Renewable Energy House
rue d´Arlon 63-67
B-1040 Brussels
Belgium
tel: +32 2 546 19 30
fax: +32 2 546 19 34

EUREC Agency represents renewable energy research centres in Europe

Publications Office
Publications.europa.eu

ISBN 978-92-79-11948-4