Strategic Research Priorities for Solar Thermal Technology

European Technology Platform on Renewable Heating and Cooling

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Heating & Cooling
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This document was prepared by a group of high-level European solar thermal experts, based on consultations with industry and research sector representatives, as well as other stakeholders. Furthermore, there was a thorough consultation process, divided into different stages, with the members of the European Solar Thermal Technology Panel (ESTTP) of the RHC-Platform, which also involved a workshop held in Brussels in December 2011. The consultation and drafting process drew on the expertise of the Dutch consultancy EnergyGO and the support of the RHC-Platform secretariat and the European Solar Thermal Industry Federation (ESTIF), with the financial backing of the European Commission, via the 7th Framework Programme.

DISCLAIMER

The opinions expressed in this document are the sole responsibility of the European Technology Platform on Renewable Heating and Cooling and do not necessarily represent the official position of the European Commission.

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FOREWORD

Dear reader,

The European Union aims at a fundamental transformation of its energy system to achieve a reduction of greenhouse gas emissions between 80 to 95% by 2050.
Today, about half the final energy demand is used for heating and cooling purposes. In future, the heat demand will be significantly reduced through behavioural changes and efficiency measures, e.g. by nearly-zero-energy-buildings. However, as heat is not only used for space heating in new builds and in the existing housing stock, but also for domestic hot water and process heating, in 2050 there will still be approximately 50% of today's heat demand.
The European Technology Platform on Renewable Heating and Cooling (RHC-Platform) is developing concepts showing how renewable energies can meet the entire heating and cooling demand in 2050. Its vision document, published in 2011, describes the RHC-Platform objectives.
Within the heating and cooling sector, solar thermal energy will play a vital role. Up to now, it has only covered a minor share of the heating demand in Europe, although it has the greatest potential of all renewable energies for heating and cooling. One of the main reasons is that the technological potential of solar thermal has not yet been developed. In the past, public budgets for solar thermal R&D programmes have been relatively small and often solely focussed on demonstration.
In this document, the European Solar Thermal Technology Panel (ESTTP) of the RHC-Platform provides a comprehensive outline of the solar thermal technologies strategic research priorities and confirms their great innovation potential. If the related research is carried out, solar thermal will be able to realize its potential and become a major energy source for heating and cooling.
We thank all the contributors to this document warmly for their valuable input and hope, that it will convince politicians, industry and the research sector of the need to increase significantly R&D activities to exploit the huge opportunities offered by solar thermal technologies.

With sunny regards
The representatives of the European Solar Thermal Technology Panel

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Executive Summary

Solar district heating plant from Ulsted Fjernvarme with an area of 5 012 m² in Ulsted, Denmark.
Source: ARCON SOLAR A/S

EXECUTIVE SUMMARY

Europe's energy future is dependent on our ability to address today tomorrow's energy challenges. These challenges must be looked at from different angles: the stability and predictability of energy costs; environmental and climatic impact of our energy production and consumption; security of supply and geostrategic political matters related to the control of the energy supply; the capacity to generate local investment and local jobs; and maintaining a technological edge. This will allow Europe to be competitive at global level in the multi-trillion renewable energy market. Today there is still a tendency to equate energy with electricity, even when it only represents less than 25 percent of the final energy consumption in Europe. Or, to regard energy production only as a centralised large scale activity, while energy is mostly consumed at a local level and on a small scale. These fallacies are also reflected in Renewable Heating and Cooling (RHC) European and national policies and action plans.

Renewable Heating and Cooling is the energy sector sleeping giant which for a long time has been misperceived and underestimated. This was acknowledged in 2011 by the European Renewable Energy Council (EREC) in its "RE-thinking 2050" publication: "As a sector, heating and cooling remains the largest contributor to the final energy demand in 2050. The renewable heating and cooling market, comprising residential and industrial biomass as well as solar thermal and geothermal applications, is predicted to take off fast. Together, they represent approximately 21% and 45% of the total final energy consumption in 2030 and 2050 respectively."

According to the Common Vision for the Renewable Heating & Cooling sector in Europe, published in 2011 by the Renewable Heating and Cooling European Technology Platform (RHC-Platform), the potential of these technologies is vast: "in 2020 over 25% of heat consumed in the European Union could be generated with renewable energy technologies" and "by 2030 renewable heating and cooling technologies could supply over half the heat used in Europe".

Solar thermal energy, together with biomass and geothermal energy, is a major source of heating and cooling in Europe. It is an extremely convenient source of heating, based on a simple concept enhanced by cutting edge technology. Thanks to technological progress solar thermal has become not only a better option for more traditional applications, such as domestic hot water production, but also an attractive alternative for new and more advanced applications such as industrial process heat.

This document describes the potential of solar thermal technologies and the most important R&D priorities that can facilitate the large deployment of solar thermal in multiple market segments.

To promote such deployment, a multi-approach strategy is needed, requiring:

- a considerable increase in the number of annually installed solar thermal systems;
- an increased solar fraction of systems per building;
- a systematic development of market segments with low solar thermal penetration, and;
- a strong support for solar thermal applications in the R&D and pilot phase by increasing both the R&D effort and the number of pilot plants.

This can be attained by means of technological achievements that:

- significantly reduce the costs of solar thermal energy for different applications and for high solar fractions;
- ensure a high system performance and reliability of solar thermal systems, e.g. by system design improvements;
- allow solar thermal to play a more important role in medium temperature applications;
- boost the combination of solar thermal systems with other technologies into hybrid systems, and;

- improve the production technology for solar thermal components and systems.

The potential, challenges and objectives, as well as the respective R&D priorities to achieve these objectives are detailed in chapter 3. Research and development needs are divided into different R&D focus areas; structured as follows:

Applications

- Solar domestic hot water and space heating systems
- Non-residential solar heating applications
- Solar cooling systems

Components

- Solar thermal collectors
- Thermal storage
- System control and performance assessment

Non-technological topics

- Standards and measures for quality assurance
- Other non-technological priorities and supporting measures

The analysis of each of these focus areas includes an overview of the state-of-the-art, the challenges, development objectives, the main R&D challenges and R&D priorities.

APPLICATIONS

Solar domestic hot water and space heating are the most common solar thermal application today. These solar thermal systems have an important development potential for improving the cost-performance ratio and building integration. The 'Solar Active House' concept is very promising, since it meets the 'Nearly-Zero Energy Building' requirements that will become compulsory in the EU in 2020. The R&D priorities aim to reduce costs, increase the solar fraction per building and to improve the reliability of solar thermal systems.

Non-residential solar heating applications are used to provide process heat for industrial and agricultural applications from low and medium temperatures; i.e. between 40°C and 95°C and 95°C and 250°C; to high temperature up to 400°C. This promising market also includes large-scale solar thermal systems for district heating. These have experienced a strong development in recent years, in particular with important projects being implemented in Denmark, Germany and Austria. In order to encourage this development in other countries, it is also important to carry out R&D on dedicated low, medium, and high temperature collectors, on enlarging the range of applications for increasing solar process heat and optimizing large-scale systems for district heating.

Solar cooling has been regarded as a very promising application for solar thermal energy in countries with high radiation and high cooling loads. This solution has been demonstrated in different configurations and applications, but currently has only a very small presence in the market. A stronger uptake hinges on cost reduction, system quality improvement, energy performance enhancement, and better building and process integration. With these objectives in mind, R&D should aim at improving thermally-driven cooling components and enhancing system performance, integration and costs.

COMPONENTS

The main element of any solar thermal system is, of course, the **solar thermal collector**. Further developments should focus on new materials (coatings and surfaces), on technical improvements (stagnation temperature limitation), as well as advanced technologies for medium and high temperature applications. New types of collectors such as photovoltaic-thermal (PVT), air and façade integrated should also be considered. The R&D priorities aim at increased performance with lower cost, simplified installation and cheaper maintenance, or even increased stability and more reliable long-term performance.

Thermal storage allows the short, medium, and long-term capture of solar thermal energy and enhanced solar fractions. However, it creates additional losses, increases the price of solar heat and can be voluminous if it is used as seasonal storage. Therefore, R&D is needed to increase storage density using thermochemical or phase change materials, to improve its reliability and efficiency and to reach more efficient storage through better heat transfer and heat transport.

To improve the management, monitoring and operation of a solar thermal system, **control and performance assessment** have gained in importance and urgency. The R&D priorities in this area should concentrate on new sensors; system integration and communication, as well as the development of advanced algorithms; and focus on exploring further the solar thermal potential of a heating & cooling system.

NON-TECHNOLOGICAL

To encourage innovation in the marketplace, new developments in terms of R&D need to be complemented by **standards and measures for quality assurance**. This requires developments in standardisation, testing and certification to facilitate a sustainable market development and improve trust among consumers, by making the best use of the European legislative framework for buildings, renewable and energy efficiency and supporting its implementation.

The development of solar thermal relies also on **non-technological research and supporting measures**, which must address the demand for a broad professional training and educational system and also the necessity to strengthen the research infrastructure related to solar thermal. Furthermore, several socio-economic aspects must be taken into account, such as awareness-raising about this technology, the development of new business models for the deployment of solar thermal systems, and the need for effective public support policies.

The “Strategic Research Priorities for Solar Thermal Technology” aims at providing a good overview for industry, research, policy makers and public authorities about the development potential of the solar thermal technology, while identifying and describing the R&D priorities which are essential for unlocking the market potential of solar thermal energy.

The research priorities described in this document have been defined within the European context, and as such, can also be extrapolated to national level.

The coming years are decisive for Europe to meet its renewable energy targets for 2020. Solar thermal can provide a reliable, cost-effective solution to increase the energy production from renewable energy sources. With adequate support measures its market uptake can be fast with an immediate impact on CO2 emissions. This capacity is today limited to smaller markets; however, with adequate investment in R&D, solar thermal can become more economical, practical and competitive in a wider range of markets and applications.

1. Introduction

Flat plate collector installation, Germany
Source: BSW-Solar/Citrin Solar

1. INTRODUCTION

1.1 WHAT IS SOLAR THERMAL?

Solar thermal technology simply converts sunlight directly into heat and makes this heat available for different applications. The primary solar thermal application is domestic hot water heating (DHW) for residential homes, since the temperature level needed is moderate (45°C to 60°C) and DHW is needed during throughout the year. Solar assisted space heating systems and process heat applications for low temperature up to 95°C, as well as for medium temperatures up to 250°C or high temperature up to 400°C are later developments. In addition, solar thermal heat can be used to drive a thermal cooling machine and can, therefore, be used as energy source for cooling.

Solar thermal systems vary according to **collector type and mounting**, **storage volume**, **control strategy and system configuration** to provide the heat required with the right temperature and the right volume at the lowest investment costs. Since solar radiation is an energy source varying daily and seasonally, the storage volume must be adapted accordingly; usually a back-up heater is included to provide the user with a secure heat supply. Therefore, solar thermal systems must be adaptable to suit different types of application, taking into account a great number of factors.

The most common **types of collectors** are flat plate and evacuated tube collectors, As they are non-concentrating collectors; they are usually used for DHW and space heating, as well as process heat applications with temperature levels up to 95°C; to provide higher temperatures usually concentrating collectors are used. For very low-temperature applications like swimming-pool heating, unglazed plastic collectors are sufficient.

As regards **system configurations**, in Central and Northern Europe the forced circulation system is used, in which the heat transfer fluid is driven through the system by a pump. In Southern Europe, simple thermosiphon systems are very popular, since they are low cost using natural convection to carry hot water from the collector to the water store placed above. They can be easily installed on flat roofs, which are common in Southern Europe. Since there the ambient temperature is also moderate in winter, the DWH storage tank can be located outside.

In many applications, collectors are placed either on flat roofs or on top of pitched roofs. However, it is expected that building integration of collectors will become more common: either roof integration, (i.e. incorporated into the roof) or façade integration (i.e. as part of the external structure, replacing walls and windows). Only in very large systems, collectors are placed stand-alone in ground-mounted arrays.

1.2 WHAT IS THE ESTTP?

Back in 2005, the European Solar Thermal Technology Platform or ESTTP was set up as a European technology platform dedicated to solar thermal technology, to strengthen the technological development of solar thermal. It evolved into its current form: the European Renewable Heating and Cooling Technology Platform (RHC-Platform) in 2008, to make the best use of synergies between the technologies. Solar thermal became one of the technology panels within this Platform.

The RHC-Platform covers renewable heating sources (biomass, solar thermal and geothermal), as well as cross-cutting topics such as heat pumps, storage, district heating and cooling as well as hybrid systems, which are highly important as enabling technologies to all three renewable energies. The European Commission endorsed the RHC-Platform in October 2008. Besides being engaged in structured dialogue with the Platform, the European Commission also supports financially the running of its secretariat.

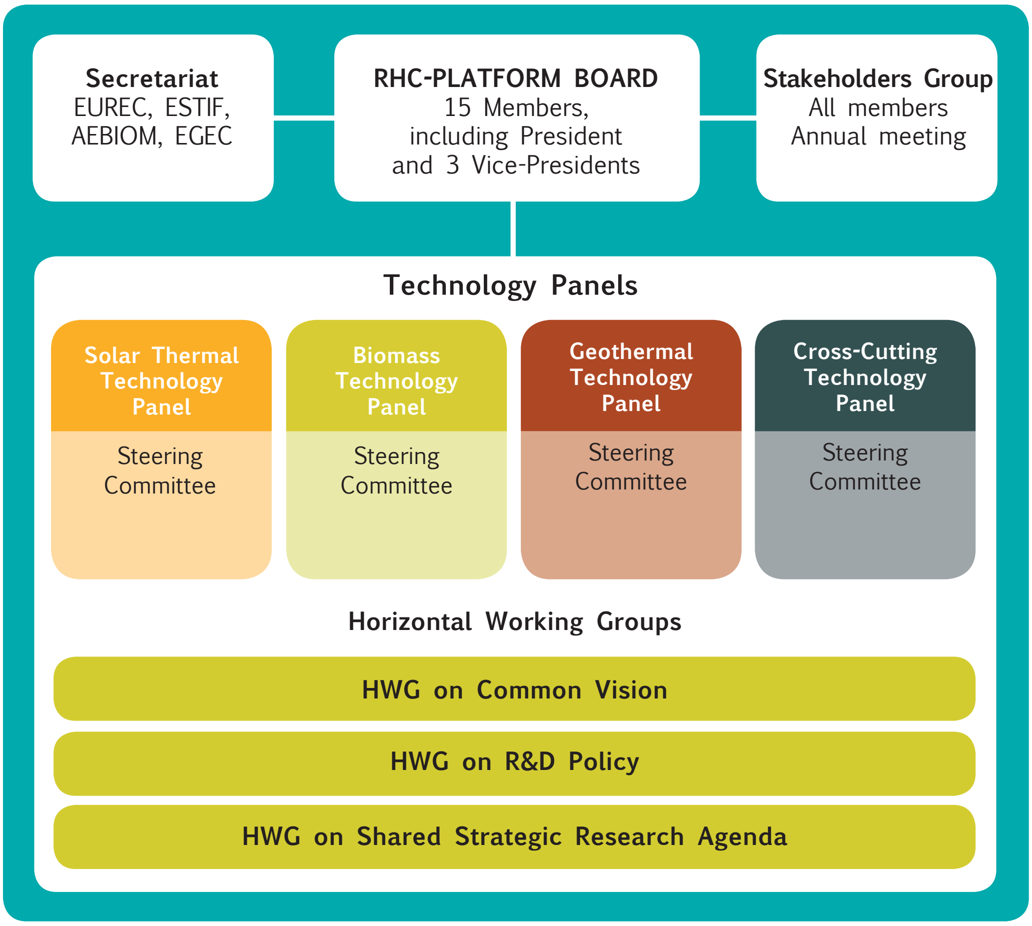

Figure 1 - Structure of the RHC-Platform

The European Solar Thermal Technology Panel (ESTTP) of the RHC-Platform consists of over two hundred experts from industry, research, services in the solar thermal field and other related sectors. These experts contribute to the work of the panel and participate in its events. The panel is managed by a Steering Committee of 15 members. The chairman and two vice-chairmen of the Steering Committee also sit on the board of the RHC-Platform, representing the ESTT panel.

The ESTTP aims at strengthening the awareness of the huge technological potential of solar thermal; identifying R&D needs and increasing R&D activities in the solar thermal sector; accelerating the development of solar thermal technology and creating conditions for a broad dissemination of advanced solar thermal technologies. Together with the other panels of the RHC-Platform, the ESTTP developed the Common Vision and the Strategic Research Agenda (SRA) for the Renewable Heating and Cooling technologies in Europe and advocates increased support for R&D on Renewable Heating and Cooling technologies.

Steering Committee of the European Solar Thermal Technology Panel of the RHC-Platform

Chairman	Gerhard STRYI-HIPP	
Vice-Chairmen	Werner WEISS & Daniel MUGNIER	
Members	Milou BEEREPOOT	Hans-Martin HENNING
	Nigel COTTON	Riccardo ROMPANI
	Jan-Olof DALENBÄCK	I. Hakki TIGLI
	Harald DRÜCK	Wim VAN HELDEN
	Daniel GONZALEZ	Thomas WILLIAMSON
	Javier GRÁVALOS	Theodor ZILLNER

Note: Composition as of mid 2012

1.3 THE STRATEGIC RESEARCH AGENDA

In 2006, the ESTTP formulated its' 2030 vision for low-temperature solar thermal applications and started to develop its Strategic Research Agenda "Solar Heating and Cooling for a Sustainable Energy Future in Europe"[1]. More than 100 European experts from the industry and research sectors have contributed to this document, published at the end of 2008. In this publication, the technological perspectives of solar thermal were systematically presented for the first time. It outlined the research efforts and infrastructure needed to reach the goal of solar thermal supplying up to half the energy needed for heating and cooling by 2030. This first SRA has become a major reference for the development of the solar thermal sector, both by its vision and by its concrete proposals in terms of priorities in the R&D field, with a definite impact on European and national support for solar thermal R&D work.

ESTTP
European Solar Thermal Technology Platform

Solar Heating and Cooling for a
Sustainable Energy Future in Europe

Vision
Potential
Deployment Roadmap
Strategic Research Agenda

Figure 2 - Solar Heating and Cooling for a Sustainable Energy Future in Europe, ESTTP Strategic Research Agenda, 2008

As a result of solar thermal technology developments over recent years, as well as the rapid growth of the renewable energy sector, boosted by the support of political instruments such as the RES Directive[2] or the recast of the Energy Performance of Buildings Directive[3], there has been a strong call for an update of the SRA, now called Strategic Research Priorities (SRP) for Solar Thermal Technology. The updated solar thermal research priorities are detailed in this document, providing a clear and concise overview of the potential and technological requirements for the development of the solar thermal sector.

This document is the outcome of the joint effort from the ESTTP members. Building on the first edition of the SRA, complemented by insights and inputs from recent national SRAs developed in countries such as Germany[4] and Austria[5], it has been consolidated by contributions from a large number of solar thermal experts from all over Europe. It is the most up-to-date overview of crucial solar thermal R&D priorities and is therefore a very important basis for the development of the solar thermal sector.

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[1] Solar Heating and Cooling for a Sustainable Energy Future in Europe, European Solar Thermal

[2] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources

[3] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings

[4] www.solarthermietechnologie.de

[5] www.solarwaerme.at/Forschung

2. Vision

Fresnel collector generating process heat at 180°C, serving the first solar-only powered cold storage at Kramer GmbH, in the framework of project AgroKühl.
Source: Industrial Solar

2. VISION

2.1 CHALLENGES AND BENEFITS OF SOLAR THERMAL

Europe's future is dependent on our capacity to address the energetic challenges of tomorrow. This means, carbon free energy must be provided, with a high security of supply, in a sustainable way and at stable costs. Solar thermal heat fulfils all these criteria with regard to the thermal energy demand. Free solar energy can be used everywhere by everyone, and therefore reduces fuel import dependencies. Since the potential of solar thermal energy is greater than the expected future heat, solar thermal energy can provide a large share of the heat demand in Europe.

However, up to now, solar thermal energy has only played a small role in Europe's energy supply since it faces two challenges.

Firstly, solar thermal energy is often still not yet cost-competitive with fossil fuels at today's prices. The correct economic way to compare solar heat prices with those from fossil fuels is to calculate these over the lifetime of the solar thermal system. Then, competitiveness is strongly dependent on the assumed growth rate of fossil fuel prices. The price of solar heat will remain stable, since costs come mainly from the initial investment. However it is highly likely that the price of fossil fuels will continue to rise. Depending on the estimated growth rate of fuel prices, the cost of the heat supplied by solar thermal applications can already be lower than alternatives using fossil fuels. However, this is usually not the type of comparison made by the short-term investor, who normally compares the long-term stable solar thermal heat price with today's fossil fuel price.

Secondly, there is a mismatch between the supply of solar irradiation and the demand for heat. For domestic hot water applications, during summer the discrepancy can be compensated with relatively small water storage to store the heat demand for about two days; however, if a seasonal mismatch must be offset, a very large storage volume will be required. Although technical solutions are available, such seasonal storage is currently only installed in pilot plants, since it increases the level of investment required and, consequently, the price of solar thermal heat rises significantly.

The challenges, therefore, are to reduce investment costs for solar thermal systems and, simultaneously, to further increase the solar fraction; as well as developing solar thermal technologies for new applications such as solar assisted district heating, industrial process heat and solar cooling. In addition, the improved integration of solar thermal into efficient heating systems, such as combined heat and power systems, and the improved technical and architectural integration of solar collectors into buildings roofs and façades are important undertakings for the sector.

To stimulate market deployment, solar thermal energy requires a stronger support policy which mitigates the effects of the unfair comparison between costs for solar thermal heat and for heat produced using fossil fuels. The comparison is biased in favour of fossil fuel costs, as these do not include negative externalities such as the environment, import dependency and other factors.

In addition, a significant increase in public support programmes and budgets for research and development is needed, to stimulate the development of solar thermal technology with higher solar fractions, lower costs, and improved efficiency and reliability. In the long run, the combination of both, increased market stimulation and increased R&D will help solar thermal to become cost-competitive and an attractive heat source in Europe, without subsidies.

There are many benefits generated by the increased use of solar thermal energy:

- **Security of supply**: Solar thermal energy will reduce the import of fossil fuels from unstable regions and will reduce the dependency on electricity for heating purposes.

- **Stable energy prices**: Solar thermal will stabilize the energy price for heating, since only the equipment has to be financed when installing the solar thermal system. Solar thermal systems will become cheaper due to economy of scale while fossil fuel prices will continue to rise.

- **Climate protection**: Heating accounts for almost 50% of the final energy demand in Europe. The goals of 20% CO2 reduction by 2020 and at least 80% reduction by 2050 can only be achieved if the heating sector reduces its emissions significantly. Solar thermal is carbon free and key to achieving the heating and cooling sector's objectives.

- **Increased added value**: The production of solar thermal systems will create added value both at national and local level. Generating local investment while reducing imports from fossil fuel producing countries constitutes a sustainable economy.

- **Long-term jobs**: Engineering, production, distribution, installation and maintenance of solar thermal systems are providing stable long-term employment at local level.

- **Technological leadership**: Solar thermal technology is most advanced in Europe with a lot of innovative small and medium sized companies designing and manufacturing solar thermal components and systems, offering a variety of solutions for different applications. However, global competition is growing; China is by far the biggest solar thermal market worldwide and is pushing ahead with technological development. To maintain its lead, the European solar thermal industry needs a strong market and increased support for research and development of the technology, as in other sectors which have faced similar competition.

2.2 STATE-OF-THE-ART

Worldwide, solar thermal energy is mainly used for domestic hot water (DHW) and space heating in single and multi-family homes. Heating DHW during the summer is one of the easiest and therefore cheapest ways of using solar thermal energy. However, other types of applications are growing. In central Europe combi-systems for DHW and space heating already achieve high market shares. Large solar thermal systems have experienced a strong growth over recent years: solar thermal process heat applications for industrial and agricultural processes; solar district heating systems with and without large seasonal heat stores and the so called collective systems used in multi-family homes, hospitals, hotels and retirement homes etc. In addition, the interest in Solar-Active-House solutions is growing: as over 50% of its heating and cooling needs are met by solar thermal heat and solar thermal assisted cooling, these houses are one step closer to the Nearly-Zero Energy House concept.

Typical solar thermal systems are:

- **Solar thermal DHW systems for single and two family homes, thermosiphon**:
  In Southern Europe, because of the high solar radiation and temperate climate, simple thermosiphon systems are commonly used. In this instance, the solar heat transfer fluid circulation is naturally driven, since the water store is installed above the solar collector. Usually 2-3 m2 flat plate collector area and a 150 litre store are used for a family of four. The solar fraction for DHW achieved is about 50% to 60%.

- **Solar thermal DHW systems for single and multi-family homes, forced circulation**:
  In Central and Northern Europe, including Northern Italy, only forced circulation solar thermal systems are used. The collector is installed on the roof and the hot water store is usually situated in the basement. The solar heated transfer fluid circulates through the hydraulic solar circuit with the help of a pump. Typically a 4-6 m2 flat plate collector area and a 300 litre store are used for a family of four. Evacuated tube collectors are used in around 15% of solar thermal systems. The solar fraction for DHW achieved is about 60%. A special version of the forced circulation type is the so called "drain-back" system, where the heat transfer fluid is pumped through the collector only when the solar system is active;, whereas it is stored in a tank while the system is inactive.

- **Combi-systems for one and two family homes**:
  These are mainly used in central Europe, especially in Germany, Austria, Switzerland and France. In addition to the DHW, these systems provide space heating. In Germany about 50% of newly installed systems are combi-systems with usually a 10 to 15 m2 flat plate collector and a 600 to 1000 litre hot water store. In a well-insulated building the solar fraction is about 25% of the overall building heat demand for DHW and space heating. In Austria combi-systems have a larger collector area of 20 to 30 m2.

- **Large solar thermal systems for large DHW consumers**:
  In multi-family homes (hotels, hospitals, residential homes, etc) with a high DHW demand, solar thermal energy can be provided through large solar thermal systems. These systems are usually forced circulation systems with the collector area on the roof and a central hot water store in the basement. A typical size is 0.5 to 1 m2 collector area per occupant and 50 litre hot water volume per m2 collector area.

- **Solar thermal process heat systems**:
  Today, approximately 40% of the heat demand is used for process heat in industry and agriculture. Solar thermal energy could cover a sizeable part of this demand. The solar thermal technology used depends greatly on the temperature level required. In some applications, e.g. for washing processes, only a low temperature of about 50°C is needed and numerous industrial processes necessitate temperatures up to 95°C. For these, temperatures mainly flat plate collectors are used, both evacuated tube collectors and improved flat plate collectors are able to provide a temperature level up to 120°C with reasonable efficiency. Higher temperature levels can be reached if the solar radiation is concentrated. Low concentrating CPC reflectors in either flat plate collectors or evacuated tube collectors can improve the performance at an operating temperature of up to 150°C. The higher concentration factors of parabolic trough or linear Fresnel collectors provide operating temperatures up to 400°C. These concentrating technologies only make use of direct sunlight and must constantly track the sun.

- **Solar-Active-Houses with high solar fraction**:
  In a well insulated single family home in central Europe, about 60% of the overall heat demand for DHW and space heating can be covered by a collector area of 30 to 40 m2 and a hot water store of 6 to 10 cubic metre. This concept is called the Solar-Active-House. A small quantity of the solar yield produced in summer is stored to be used during the heating period, complementing the significant amount of heat produced by the large collector area in winter. The minimum solar fraction of a Solar-Active-House is 50%, but it can be increased to 100% by enlarging the collector area, the thermal storage volume, and the building insulation.

- **Solar district heating systems with and without seasonal heat storage**:
  Buildings that do not have sufficient roof area to produce enough solar energy on their own can be supplied with solar thermal energy via a district heating (DH) network. The DH can supply high-density urban areas with different renewable energies and combined heat and power (CHP) plants. In some countries like Denmark, the share of DH is very high and large solar thermal collector fields are often connected to district heating systems. In Denmark, Germany, and Sweden, special solar district heating pilot systems integrate a large, seasonal heat store with a water volume of several ten-thousand cubic metres to increase significantly the solar fraction of the DH system. Since the surface of these stores is small compared with the volume, their heat losses are very low, as are their specific construction costs. Therefore, a large share of the space heating demand in the heating season can be provided by solar energy harvested in summer.

- **Solar thermal assisted cooling**:
  Since the cooling demand is increasing all over Europe, the extra electricity required for cooling machines during the summer is a growing burden on the electricity system. Solar thermal assisted cooling is a very interesting option, helping to reduce electricity peak loads during summer. Several hundred solar thermal assisted cooling pilot systems are already installed in Europe and their functionality is proven. However, the technological development is still in its infancy, since efficiency must be further increased and costs reduced to compete in the cooling market.

2.3 MARKET OUTLOOK

The European solar thermal market grown considerably between 2002 and 2008: it increased over fourfold during that period. Since the start of the economic crisis, the market has declined by around 25% to 2.6 GW thermal newly installed capacity in 2011. Solar thermal energy is still in the very early stages of market development, as currently only about 0.3% of the heat demand in Europe is provided by solar thermal energy.

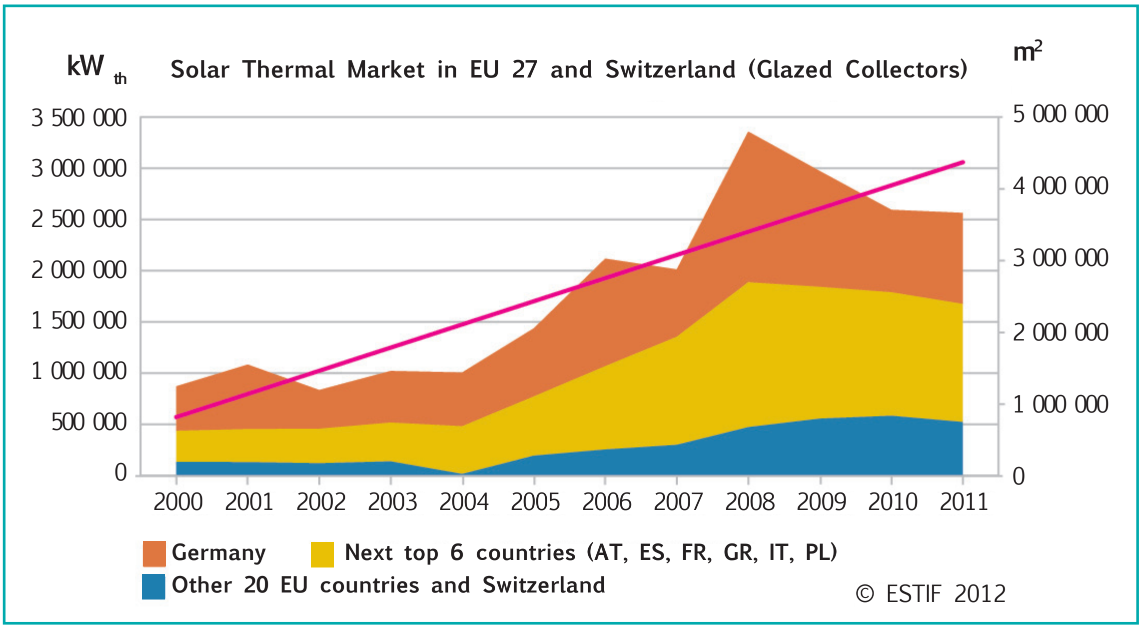

Figure 3 - Annually installed solar thermal capacity in EU 27 and Switzerland (left axis in kWth, right axis collector area in m²). Source: ESTIF

According to the European Member States National Renewable Energy Action Plans, from 2010 the total solar thermal capacity installed will quadruple between 2010 and 2020 and the collector area will increase to 0.26 m2 per capita, representing a share of solar thermal heat of 1.2%. However, a potential study commissioned by the European Solar Thermal Industry Federation (ESTIF) showed that, by 2020, it would be feasible to reach an installed collector area three times greater, i.e., 0.56 kWth (0.8 m²) per capita.

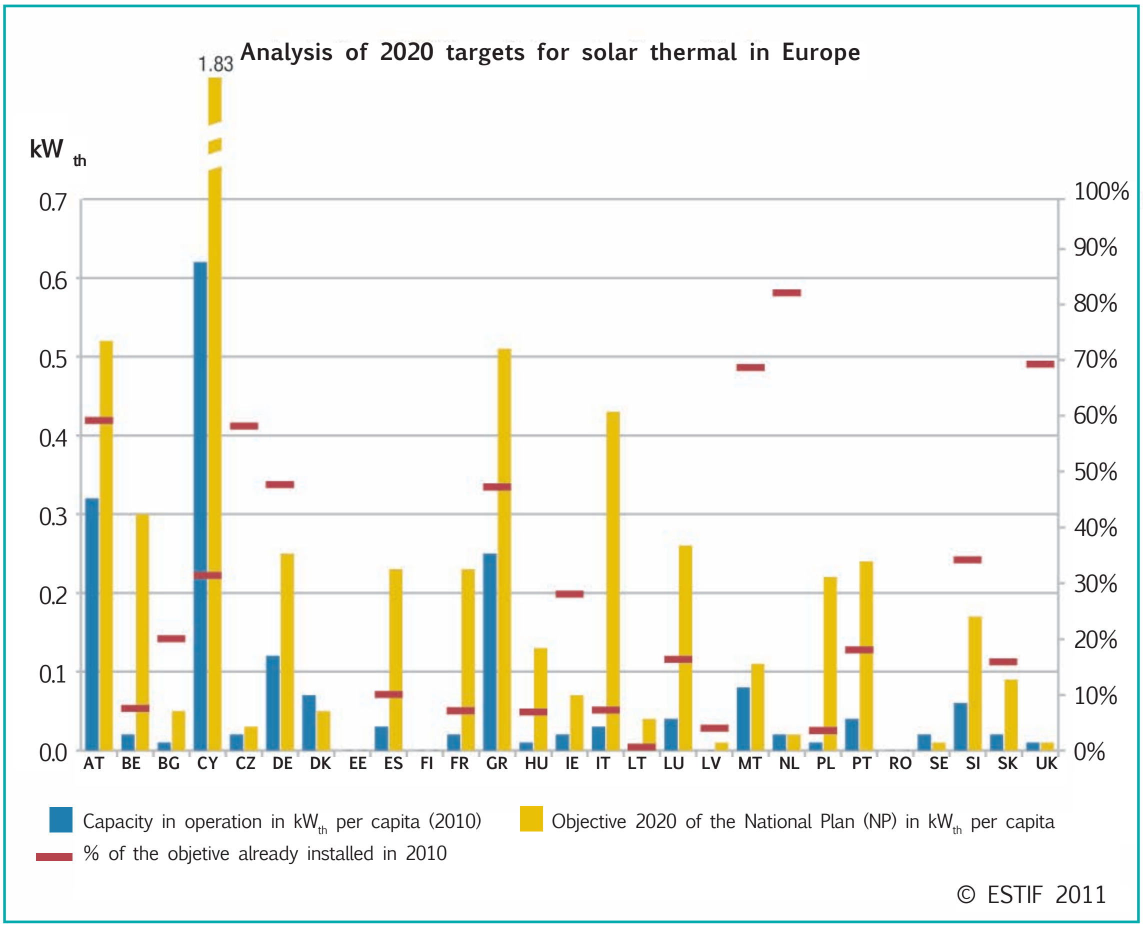

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Figure 4 - Comparison between the solar thermal installed capacity per capita in 2010 and the national targets for 2020 in EU27. Source: ESTIF

To increase significantly the share of solar thermal energy in Europe, a multi-approach strategy is necessary:

- the annually installed number of solar thermal systems must be increased considerably;
- the solar fraction of systems per building must also be increased;
- the market segments with low solar thermal penetration must be systematically developed, and;
- the solar thermal applications in the pilot phase must be supported by increasing both the R&D effort and the number of pilot plants.

The solar thermal market development over the last decade shows its strong dependency on external factors. This has meant great uncertainties in market forecasts and reinforces the need for a strong political support to accelerate the market uptake of solar thermal. The demand for solar thermal systems is mainly dependent on the following factors:

- **The uncertainty of future fossil fuel energy prices**:
  Experience shows that the demand for solar thermal systems is strongly linked to the price of fossil fuels. Due to the high unpredictability of fossil fuel prices, it is almost impossible to make a serious comparison between the price of solar thermal energy and fossil fuels over the lifetime of the solar thermal system.

- **The uncertainty of future heating technologies**:
  New heating technologies are already available on the market such as pellet stoves and heat pumps, while other technologies such as micro-CHP systems, stirling engines or fuel cells are launched. Since investors are uncertain about the relevance and competitiveness of new technologies, and since heating investments are long-term , a lot of investors are waiting and postponing their decisions;

- **The uncertainty on the political front**:
  The political targets are set at European and national level, e.g. the 20% target of renewable energy and the nearly zero energy building requirement by 2020. However, the relevant policy to achieve these goals is not yet implemented at national level and investors are hesitant about future requirements. This results in reluctance to invest in solar thermal energy;

- **The uncertainty of political support programmes**:
  Most European countries have published support programmes for solar thermal energy over the past decade. However, often policy and programmes were incoherent and inconsistent, budgets for subsidies were not sufficient and this resulted in stop-and-go policies. This weakened investors' confidence in solar thermal technology;

- **The different levels and quality of support programmes**:
  Many investors have come to realize over recent years that electricity generation from photovoltaic, wind and bio energy was strongly supported by feed-in tariffs, which made their investments profitable. In contrast, support for solar thermal energy has usually been only through a small incentive or stimulus, which has not helped close the competition gap with fossil fuels. In addition, the risk from the incidence of energy price on the competitiveness of the solar thermal technology is borne by the investor, whereas with the feed-in tariff scheme it is passed on to the electricity consumer. Therefore, a lot of investors prefer to invest in renewable electricity generation.

Therefore, the short-term solar thermal market development is greatly affected by fluctuations in the price of fossil energy and the support policy from European member states. To achieve the European goals it is essential to win greater political support for market deployment and for R&D in order to stimulate the markets and compensate for such uncertainties.

If the sector receives the support needed to overcome the short-term challenges, the outlook for the long-term market development is very positive. Since it is anticipated that the fossil fuel energy price will continue to rise and consequently, the competitive edge of solar thermal energy will improve. Furthermore, solar thermal energy will become more attractive thanks to cost reduction and technological improvements. Another medium to long-term driver of the solar thermal market is the security of supply, which is a major benefit of solar thermal energy. Since everyone can use solar thermal freely everywhere, only the availability of the solar thermal technology and the related costs are preventing the success of the solar thermal energy market.

2.4 COST COMPETITIVENESS

Solar thermal technologies are usually referred to as sleeping giant, since their market potential is not yet unlocked. Besides other aspects, costs are an important barrier, since solar heat is usually regarded as uncompetitive with heat produced with fossil fuels. However, this is not really true since there are many cases where solar thermal energy is already cheaper than heat produced by fossil fuels or electricity.

There are two reasons, why people usually do not have a clear picture of the competitiveness of solar thermal energy. Firstly, there is not 'one price' for solar thermal heat, since solar thermal systems vary greatly, reflecting different system types, qualities, and standards by the integration into the building (e.g. it is much easier to install a compact thermosiphon system on a flat roof in Southern Europe than to install a collector on a pitched roof with the solar storage in the basement which is usually the case in Central and Northern Europe). Additionally, the yield of a solar thermal system depends on the insolation (solar radiation) intensity at the installation site, a solar thermal system in Southern Europe has the same energy yield than a system with a 50% larger collector area in Northern Europe. The prices for heat from fossil fuels and electricity vary a lot across Europe. Therefore, competitiveness must be calculated for each system type, for each installation, and in comparison with the specific heat costs of the alternative heat source.

Secondly, costs for solar thermal heat are usually incorrectly compared with today's prices for fossil fuels or electricity, as the two types of costs differ considerably. Consumers consider the price of the kWh from natural gas or oil if they are aware that one litre of heating oil or one cubic re natural gas corresponds to about 10 kWh. What is the cost of solar energy, if the sunshine can be used free of charge? The investment costs plus the operating and maintenance costs during the lifetime of a system, e.g. 20 years, are taken into account to calculate solar heat costs, these are then divided by the solar heat generated during that period. These costs represent the average costs for solar heat per kWh over the entire lifetime. To achieve a fair comparison with costs for heat from fossil fuels or electricity, their average costs should be calculated over the next 20 years as well. Since oil and gas prices vary a lot, the costs comparison depends greatly on the assumption made for the energy price growth rate over the next 20 years, which is highly unpredictable. If the growth rate remains high, as in the past decade, most solar energy applications are already cost-competitive, whereas if the price remains static, solar thermal energy is largely uncompetitive. However, generally consumers do not calculate average fossil heat prices over 20 years, but are only aware of today's fossil heat prices. Therefore, they systematically underestimate the competitiveness of solar thermal energy, since there is a high probability that fossil and electricity energy prices will rise significantly.

Figure 5 shows typical ranges of solar heat costs for different solar thermal systems in different European regions, representing average heat costs over the lifetime of the systems of typically 20 years, compared with the costs for useful heat produced by natural gas and electricity in the year 2011. Even though this is an unfavourable comparison for solar thermal, as average solar thermal energy costs over lifetime are compared with today's gas and electricity prices, solar thermal energy is already in some cases cheaper than heat from natural gas and is in most cases cheaper than heat from electricity. However, for combi-systems in central Europe, where the large solar thermal markets are located, solar thermal heat costs are significantly higher than the price for heat from natural gas, which is mainly used as an alternative. Since industry is usually expecting a short payback time for investments, competitiveness of solar thermal process heat is only given, if it is significantly cheaper than heat from fossil fuels which is usually not yet the case.

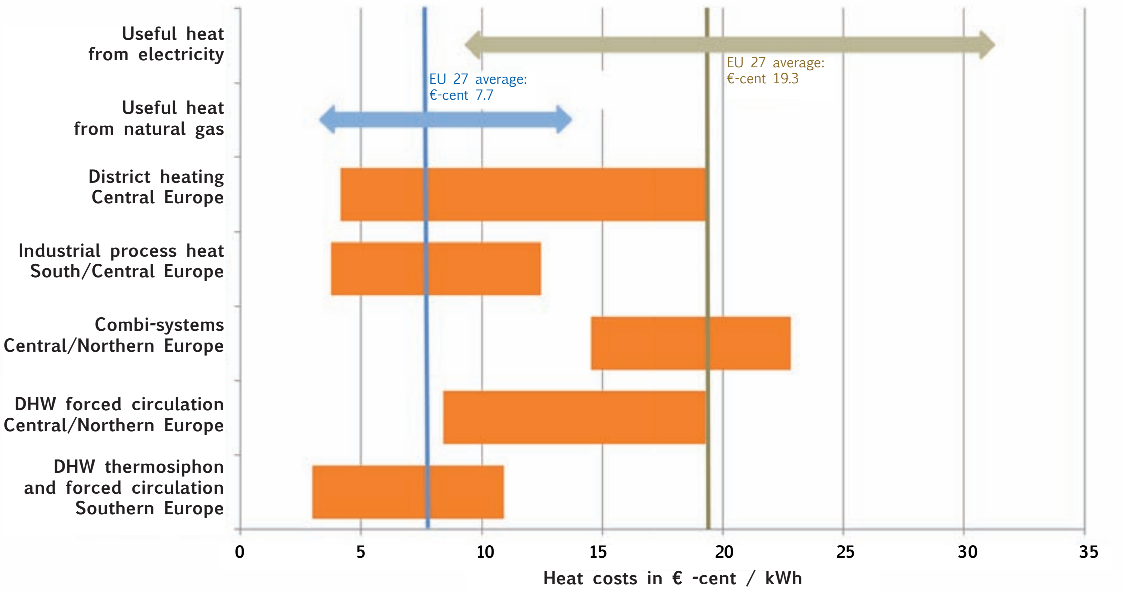

Figure 5 - Range of solar thermal heat costs for various types of solar thermal systems in different European regions (average costs over lifetime), compared with the range of costs for useful heat. Useful heat takes into account losses by converting natural gas and electricity into heat. The conversion efficiency of 85% for gas and 95% for electricity is assumed. Heat costs from natural gas and electricity are taken from 2011 and include VAT. Solar cooling systems are not included since cooling and heating prices are not comparable and a matured solar cooling market does not yet exist. However, cooling costs of about 45 Eurocent per kWh were achieved in solar cooling pilot plants and average costs for heating and cooling of about 20 Eurocent in combined heating and cooling pilot plants. Source: ESTTP, Eurostat (for natural gas and electricity).

Solar thermal heat costs are mainly determined by the upfront investment consisting of: the solar collector, storage, plumbing, pumps, controller as well as other components, and the installation costs. The investment depends on the type and size of system used, varying from below 300 EUR per kWth for large-scale district heating systems up to 1700 EUR per kWth for a combi-system. In addition, financing investment costs, operation and maintenance (O&M) costs over the lifetime of 20 years (15 years for low price thermosiphon systems) are taken into account by calculating the average solar thermal heat costs over the lifetime of the system. Based on these assumptions, the ranges of costs for solar thermal systems are as follows: between 3 and 11 Eurocents per kWh for small solar domestic hot water (DHW) thermosiphon systems in Southern Europe; between 5 and 10 Eurocents per kWh for larger solar forced circulation DHW systems in Southern Europe; between 8 and 19 Eurocents per kWh for small and collective solar DHW in Central and Northern Europe; between 14 and 13 Eurocents per kWh for solar combi systems for DHW and space heating in Central and Northern Europe; between 4 and 12 Eurocents per kWh for solar industrial process heat systems in Southern and central Europe; and between 4 and 19 Eurocents per kWh for solar district heating systems both without storage and with very large seasonal storage. The figures given are representing the costs for solar heat produced by the collector (at the collector outlet) including VAT. According to Eurostat data[6], natural gas and electricity costs to domestic consumers in the European Union range between 2.76 to 11.65 Eurocents/kWh for natural gas and between 8.74 to 29.75 Eurocent/kWh for electricity[7].

Since solar thermal heat is often not yet competitive, many of the R&D priorities described in this document are focussing on cost reduction. The potential of cost reduction is still vast, since solar thermal technology is still in its infancy, dating back only 30 years with low budget R&D programmes from the European Union and a few member states.

How quickly could the cost reduction materialize if sufficient R&D support is given and the market develops well? This can be derived from the lower solar thermal collector production costs achieved over the past 15 years, which are shown in *figure 6*. Since 1995, production costs have been cut by nearly 50%, which corresponds to a learning factor of 23%.

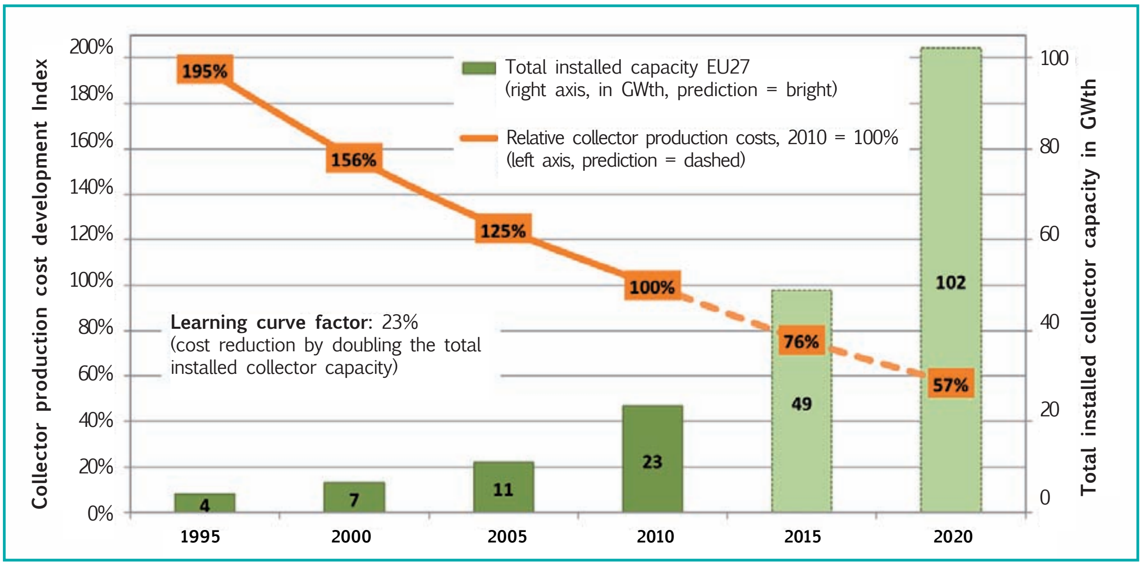

Figure 6 - Collector production costs development for high-efficient flat plate collector panel of about 2.2 to 2.5 m² gross collector area manufactured in Europe (Source: solrico & trenkner consulting). Based on a learning factor of 23%, derived from these historical data, cost reduction projections are calculated up to 2020 based on market expectations of the National Renewable Energy Action Plans (NREAPs).

To calculate solar heat costs, the installed solar thermal system price is more relevant than the collector production costs. Dependent on the size of the system, costs for the collector area represent typically between 20% and 40% of the whole system. However, today's system prices cannot be compared with prices in the past, since in the meantime both the quality and the solar fraction of systems have improved significantly by an increased efficiency and larger collector areas. On the other hand, in recent years prices have rather stagnated, since lower components prices were often offset by increased distribution and installation costs.

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[6] EU energy in figures – Statistical Pocketbook 2012, European Commission, 2012

[7] Reference gas prices to domestic consumer during the second semester of 2011 range between 7.68 EUR/GJ in Romania and 32.37 EUR/GJ in Sweden. Electricity prices, to domestic consumer varies from 8.74 EUR/100 kWh in Bulgaria and 29.75 EUR/100 kWh in Denmark.

[8] A learning factor of 23% means that by doubling the total sold collector area, production costs were cut by 23%.

In some countries, the installation costs of small domestic hot water systems may reach 50% of the investment. Therefore, R&D is also focussing on faster, simpler and fail-safe techniques for installation e.g. by developing compact solar thermal systems or standards for hydraulic connections, which will help to reduce the installation costs considerably. Besides the socio-economic context, the installation costs depend greatly on the availability of qualified workforce. In this connection, RES Directive requirements - in particular Art. 14 requesting Member States to provide, by 31st December 2012, certification or equivalent qualification schemes for installers of building-integrated biomass stoves and boilers, shallow geothermal energy systems, heat pumps, photovoltaic and solar thermal systems so that they can be mutually recognized - is expected to have a positive impact on installation costs. In addition, research and development will play an important role in the development of new collectors and solar thermal systems; new designs and materials will also make installation easier and faster, resulting in lower overall costs.

Based on the improvements stimulated by the R&D activities described in this document it is expected that the price of components and systems, as well as installation, will continuously decrease and can finally be halved by 2020 for solar thermal systems with the same solar fraction and solar yield than today.

3. Research and development needs

Indoor solar test bench, Institut National de l'Energie Solaire, France Source: P.Avavian / CEA-INES

3. RESEARCH AND DEVELOPMENT NEEDS

In this chapter, the Strategic Research Priorities are described in detail; highlighting which topics R&D should focus on up to 2020 and beyond in order to achieve the vision of the solar thermal sector. The eight sections of this chapter are covering applications, components and non-technological aspects. Applications are divided into three sections: solar domestic hot water and space heating systems (3.2), non-residential solar heating applications (3.3) and solar cooling systems (3.4). Components are divided into: solar thermal collectors (3.5), thermal storage (3.6) and system control and performance assessment (3.7). Non-technological aspects are divided into: standards and measures for quality assurance (3.8), and non-technological priorities and supporting measures (3.9). Each section is subdivided into four parts: description of the state-of-the-art, development objectives, main R&D challenges, and R&D priorities.

3.1 SOLAR DOMESTIC HOT WATER AND SPACE HEATING SYSTEMS

Currently, solar thermal systems are mainly used in residential buildings for domestic hot water (DHW) and space heating and, mainly, installed in single-family homes; however, the market share of solar thermal systems for multi-family homes is growing and in some countries, such as France, it is already around 50 %. In residential buildings there is a constant hot water demand throughout the year, which can be heated easily by solar domestic hot water systems during summer and partly during winter. Hot water storage tanks are used to offset the mismatch between sunshine and DHW demand for some hours or a few days. In Central and Northern Europe, the main heat demand is needed for space heating, but only during the winter season. This demand profile is contradictory to the solar heat generation profile; therefore solar thermal combi-systems mainly contribute to space heating in the autumn and spring and need larger hot water storage tanks. The solar fraction of the space heating demand can be increased to 50% and over by increasing the collector area and the storage volume. However, since the solar energy produced, which cannot be used due to a lack of heat demand during summer increases, the system efficiency is lower with higher costs per kWh.

3.1.1 STATE-OF-THE-ART

In Southern Europe, solar domestic hot water (SDHW) preparation is mainly supplied by thermosiphon systems. These systems, robust, efficient and easy to build, consist of a solar collector with a capacity between 0.7 and 2.1 kWth (between 1 and 3 m²) and a hot water storage unit with a volume of usually 80 to 150 litres for a family of four. A thermosiphon system relies on the natural convection principle to circulate the heat transfer liquid between collector and storage. In this type of installation storage must be above the collector.

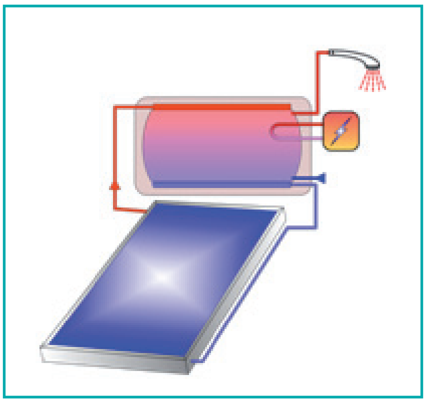

Figure 7 - Solar thermal thermosiphon system for domestic hot water preparation

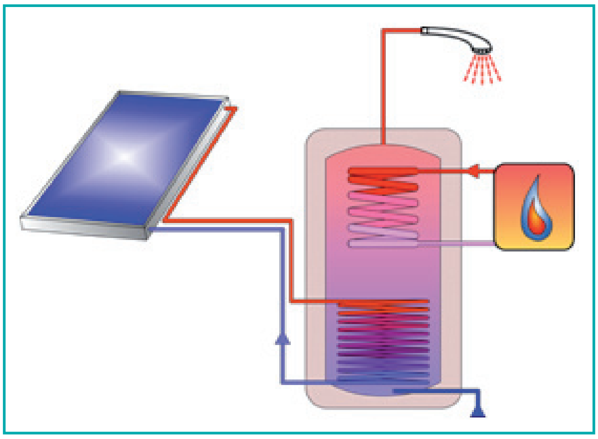

Figure 8 - Solar thermal forced circulation system for domestic hot water preparation

Forced circulation systems using a pump to move the heat transfer fluid between collector and storage are almost exclusively used in Central and Northern Europe, since it is not usually possible to install the storage tank on the roof above the collector. In addition, the integration of the solar thermal system in central heating systems is easier if the storage tank is located within the dwelling (typically the basement). In Central and Northern Europe, a typical SDHW system consists of 2 or 3 solar collectors with a capacity between 2.1 and 4.2 kWth (3 to 6 m²) and hot water storage with a volume of 200 to 400 litres for a family of four. In multi-family homes, the solar collector area depends on the size of the building, e.g. in France, a typical system has a capacity about of 35 kWth (collector area of about 50 m²) and a hot water storage tank of about 2500 litres.

Solar thermal systems providing heat for both DHW preparation and space heating are called 'combi-systems'. They prevail in Central and Northern Europe. Typically, in a single-family home a system with 7 to 14 kWth of capacity (collector area of 10 to 20 m²) and a storage volume of 500 to 1500 litres are installed. Between 20% and 30% of the total heat demand required for DHW and space heating is provided by these combi-systems in insulated buildings in central Europe (e.g. Germany, Austria and Northern France) and up to 60 % in sunny regions, such as the South of France, Italy and Northern Spain. The solar combi-systems market share is continually growing and in some countries, such as Germany, it is already around 50 %.

Today, most of the solar thermal systems are built using system packages provided by solar thermal manufacturers and system vendors. There is a wide variety of systems in the market, combining different types of collectors, storage, controllers and hydraulic equipment. Reducing the large number of different systems could result in lower costs and simpler solar thermal systems installation.

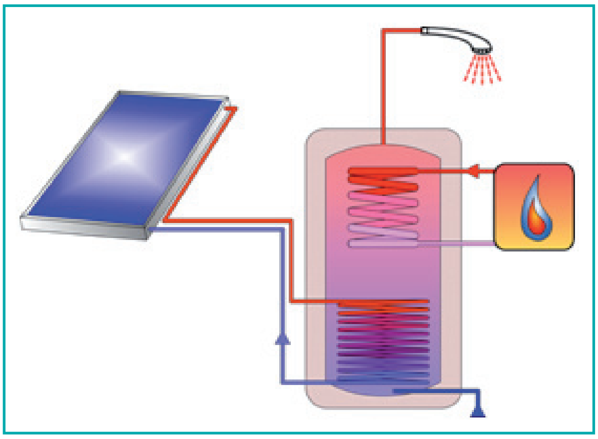

Figure 9 - Solar thermal combi-system for domestic hot water preparation and space heating

Figure 10 - Solar-Active-House with a large thermal energy storage and large solar collector field

Countries such as Austria and Germany are keen to see an improvement in the solar fraction of combi-systems; from around 25% to above 50 % and even up to 100 %. In well-insulated single family homes, a solar fraction of 60% can be achieved with a collector area over 30 m2 with hot water storage above 6 m3. A building with a solar fraction above 50 % is called 'Solar-Active-House'. More than 1000 of these houses have already been built in central Europe.

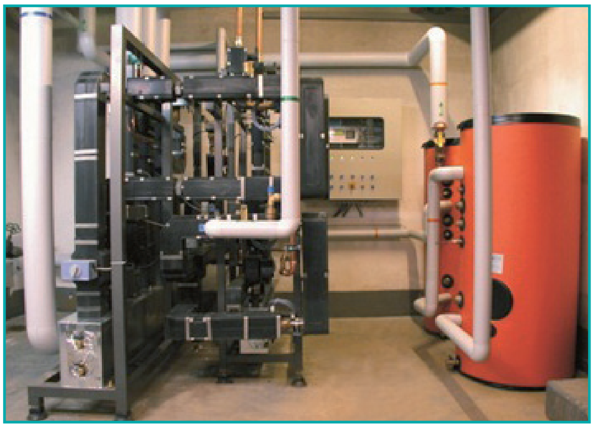

Figure 11 - Compact prefabricated hydraulic station for solar thermal systems in multi family homes. Source: Solvis.

3.1.2 DEVELOPMENT OBJECTIVES

By intensifying R&D efforts for solar thermal applications in the residential sector some ambitious objectives can be achieved.

The competitiveness of solar thermal systems will be significantly increased by halving costs by 2020, by improving the reliability of solar thermal systems through technical innovations, and by introducing optimized compact solar hybrid heating units.

Solar thermal technology can play a major role in achieving the European objective of 'Nearly Zero Energy Buildings' for new buildings with 'Solar-Active-Houses', which provide between 50% and 100% of the heat demand for domestic hot water and space heating by solar thermal energy. Increasing the solar fraction of buildings is prerequisite to exploit the huge potential of solar thermal energy.

Solar thermal technology will offer attractive solutions for the energy-related refurbishment of existing buildings with prefabricated multi-functional solar façade systems, combining building insulation, heat and electricity generation by solar thermal and photovoltaic panels, ventilation services and the use of daylight through integrated windows.

Figure 12 - Façade integrated flat-plate collectors in Austria. Source: DOMA

3.1.3 MAIN R&D CHALLENGES

Theme 1: Reducing costs and increasing reliability of solar thermal systems

Costs per solar heat unit could be halved by 2020 through improved system performance and lower component, as well as, installation costs. With regard to components R&D is needed to develop innovative construction concepts, new materials and improved production methods. With regard to systems, R&D is necessary to develop smart systems based on simplified design, cost-efficient components and optimised control strategy, which provide good system efficiency at lower costs and improved reliability on installation and operation. The development of standard hydraulic and electrical connections between all components is one measure which will help towards reducing installation costs, allow inter-changeability and increase reliability due to fail-safe installation (plug and function). The reliability of solar thermal systems must be increased by the integration of monitoring and self-detection functionalities.

Theme 2: Developing cost-competitive compact solar hybrid heating units

Currently, the complexity of combining solar thermal with another heat source is confusing for customers and installers. The development of easy to install and operate compact solar hybrid heating units, combining the solar thermal and back-up heating system into one, will make solar thermal energy more attractive. R&D is needed to identify the most energy-efficient and cost-efficient hybrid system designs. Assessment criteria must be developed taking into account economic and ecologic aspects both from a short-term and a long-term perspective. System technologies and adapted components, including Information and communications technologies (ICT), must be developed as well as tested to achieve smart solutions, low costs, high reliability, ease installation and operation at a high solar fraction.

Theme 3: Developing 'Solar-Active-Houses' with high solar fraction

The widespread use of solar thermal energy is closely connected to the deployment of the 'Solar-Active-House' with a solar thermal fraction of above 50% by 2020 and up to 100% by 2030. R&D is needed to develop cost effective and reliable solar thermal systems with high solar fractions. In addition to improved key components, other relevant factors include: an optimized system design to facilitate low-cost high efficiency; effective adaptation of the solar thermal system to the individual building characteristics and to the location; well-designed integration of collectors into the building envelope and of storage into the building structure; as well as high reliability and ease of operation of the system. New system concepts must, therefore, be tested and evaluated, and planning and design tools as well as standards developed.

Theme 4: Developing prefabricated multifunctional solar façade systems

Most buildings in Europe will be retrofitted within the coming years to reduce their energy demand significantly. Solar thermal systems integrated in multi-functional façade systems could become a cost-effective solution for refurbishing the building stock and allow a solar fraction above 50%. R&D is necessary to develop solar thermal collectors as an integral element of the façade, to meet the challenges of incorporating the hydraulic system and combining the solar collector with other functional systems such as insulation, ventilation and heat distribution. The objectives are easy maintenance, reduced risks of system failures and, by combining solar thermal collectors with other elements of the façade system, to fulfil the aesthetical expectations of architects and home owners with different surfaces and colours. Generally, façade collectors must comply with building regulations such as statics, as well as, weather and noise protection. The multi-functional solar façade system could be a part of a multi-functional building system as well, which includes the solar façade collectors on the outside, a heat distribution system on the inside and a heat store in between, integrated in the wall.

3.1.4 R&D PRIORITIES

R&D priorities for residential solar thermal applications are:

up to 2020	beyond 2020
Development of : • compact, long life cost-effective solar hybrid heating systems including solar thermal and back-up heater, with low operation and maintenance (O&M) costs • optimized system designs and design tools for a solar fraction above 50% in the 'Solar-Active-House' • new components and system designs for multifunctional solar façade elements and systems • concepts to integrate multi-functional elements with solar thermal systems into the construction and logistic chain of the construction sector • universal hydraulic and electric interconnections for all components of the building equipment • concepts on system level to avoid overheating and other critical operation points Testing and evaluation of : • 'Solar-Active-Houses' with a solar fraction above 50% equipped with latest system technology	Development of : • optimized system designs and design tools for 'Solar-Active-Houses' with a solar fraction of 100% • adapted system designs based on new collector and innovative heat storage technologies with increased thermal energy density • highly integrated compact solar thermal heating and cooling systems providing DHW during the year, space heating in the heating season and cooling in the summer season • improved multi-functional solar façade elements and systems with additional functionalities and high flexibility regarding the architectural integration Testing and evaluation of : • 'Solar-Active-Houses' with a solar fraction of 100% equipped with latest system technology • Multi-functional building components using solar thermal technologies available from 2020 onwards

3.2 NON-RESIDENTIAL SOLAR HEATING APPLICATIONS

Besides residential applications, solar thermal energy has a huge potential for heating purposes in the industrial sector for production and maintenance, as well as in the service sector for hotels, hospitals, care homes, swimming pools, carwash facilities and other applications. These applications are very interesting for solar thermal heating systems, since often the daily heat demand is constant throughout the year with only weekend breaks. To achieve best performance at low costs, solar thermal systems for such applications are usually designed to require only a relative small storage volume. In industrial applications the size of the collector field is often limited by the available collector installation area.

Solar thermal systems for district heating are considered as non-residential as well. Today, most of the solar district heating systems are designed for a low solar fraction with small storage volumes. However, in several pilot systems very large seasonal stores with thousands of cubic metres of water are installed to store the solar heat generated during summer to meet the heating demand in winter. It is expected, that, in future, such systems will be used more often since they result in an increased share of renewable energies for heating purposes also in high density urban areas.

3.2.1 STATE-OF-THE-ART

Solar thermal energy can be used for process heating from small systems of only a few kWth up to very large systems with thermal power of several MWth. There are applications for solar thermal systems in different temperature ranges: low temperatures from 30°C up to 95°C, e.g. for washing processes; medium temperatures from 95°C up to 250°C, e.g. for processes involving steam such as pasteurization or drying processes and high temperatures from 250°C up to 400°C. Typical industries with high heat demand are brewery, dairy, food processing, pharmaceutical, pulp and paper industries, as well as seawater desalination in some countries.

Up to now, the use of solar thermal energy for industrial processes has been rather limited, since it is often difficult to meet the expectations of the industry regarding pay-back time and flexibility of the solar thermal system. Often steam is used as transport medium even if the temperature needed at the point of use is considerably lower. In these cases, either steam must be produced with solar thermal energy or the heat distribution structure must be reorganized. Since it is more costly, to produce higher temperatures with solar energy, this affects the economy of the solar thermal system. Therefore, solar thermal energy is mainly used in such systems to preheat cold feed-in water for the steam process. Often, solar thermal heat would suit the heat demand of a process regarding temperature and load profile, however feeding-in solar heat into the process would need modifications of the machinery, which usually is not acceptable to the industry. Furthermore, industry often benefits from lower energy costs than private households, which makes it more difficult to achieve break-even points in a short period of time, even though heat generation with solar thermal fits in very well with the heat demand of industry in numerous applications.

Figure 13 - Mash tun of the Hütt Brewery in Kassel (Germany). In the background, solar heating system (155m² flat plate collectors) integrated into the hot water buffer of the brewer (pilot plant realized within project "SOPREN – Solar process heat and energy efficiency")
Source: Institute of Thermal Engineering, University of Kassel

The use of solar thermal energy in the commercial and industrial sectors, including agriculture, and water treatment applications, is currently insignificant compared with residential applications. Only a few hundred large solar thermal plants are currently installed worldwide at industrial sites. This is in spite of the fact that the industrial heat demand, including process heat, space heating and hot water, accounts for 75% of industry's final energy consumption.

District heating also provides a very high potential for using solar thermal energy. In some European Countries, such as Denmark, district heating has already a major share of the heat supply. It is expected that the number of district heating systems will grow in other countries as well, since they make it possible to use renewable energies for heating in high density urban areas, using combined heat and power (CHP) plants, as well as industrial waste heat.

Up to now, solar district heating (SDH) is in most European countries non-existent or an undeveloped niche market. Only 1% of the solar collector area in Europe is currently connected to SDH systems. However, in some countries, especially in Denmark, this market is buoyant as district heating systems are widespread there and solar thermal energy is cost-competitive due to several factors, e.g. the high price of fossil fuels. In other countries, such as Germany, the number of buildings connected to district heating is also increasing, but solar thermal energy is not usually cost-competitive with CHP plants.

Figure 14 - The world's largest district heating plant with 25MWth installed capacity (36.000 m²) in Riadh is equipped with European collector technology. (Source: AEE INTEC)

In most district heating systems, the solar fraction of the heat produced is small and no large heat storage required since the solar heat produced can be used directly. However, the solar fraction can be increased by enlarging the solar collector area and installing seasonal heat storage to store the solar heat generated in summer until the heating season. The thermal losses of such a very large storage of several thousand cubic metres are very low, the surface area being very small compared with the volume. A couple of pilot solar heating plants with seasonal storage - mainly built in Scandinavia and Germany - have proved that this type of systems can reach high solar fractions of over 50%. In South European climates with a shorter heating season, it is easier to achieve high solar fractions.

In Europe there are approximately 175 large-scale solar thermal plants above 350 kWth in operation with a total installed capacity of 319 MWth thermal power. The largest European plant is located in Marstal, Denmark with 23.3 MWth (33 000 m²). These large-scale systems are mainly used for solar district heating.

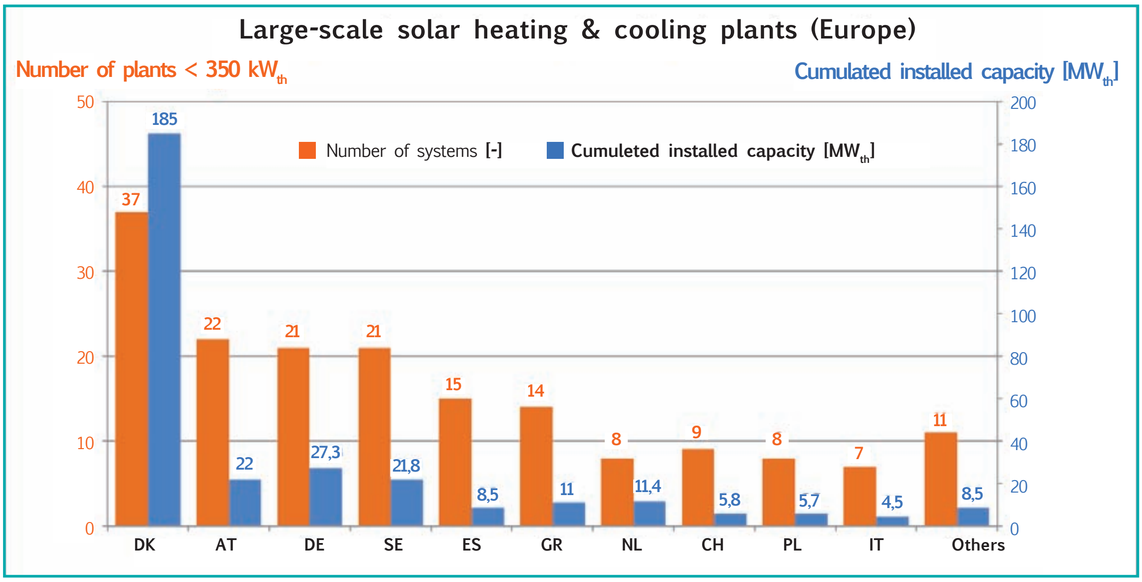

Figure 15 - Number and installed capacity of large solar thermal plants installed in European countries by October 2012. Source: Jan-Olof Dalenbäck (Chalmers University of Technology, SE)

Due to their size, and because they must be adapted to each specific application, large-scale systems for solar district heating, industrial process heat, agricultural and water treatment applications are tailor-made systems. Project engineering is needed for these large-scale systems, whereas small-scale systems can be pre-fabricated to a greater extent.

This potential can be further increased by combining solar thermal district heating systems with smart electrical grids in Smart Cities.

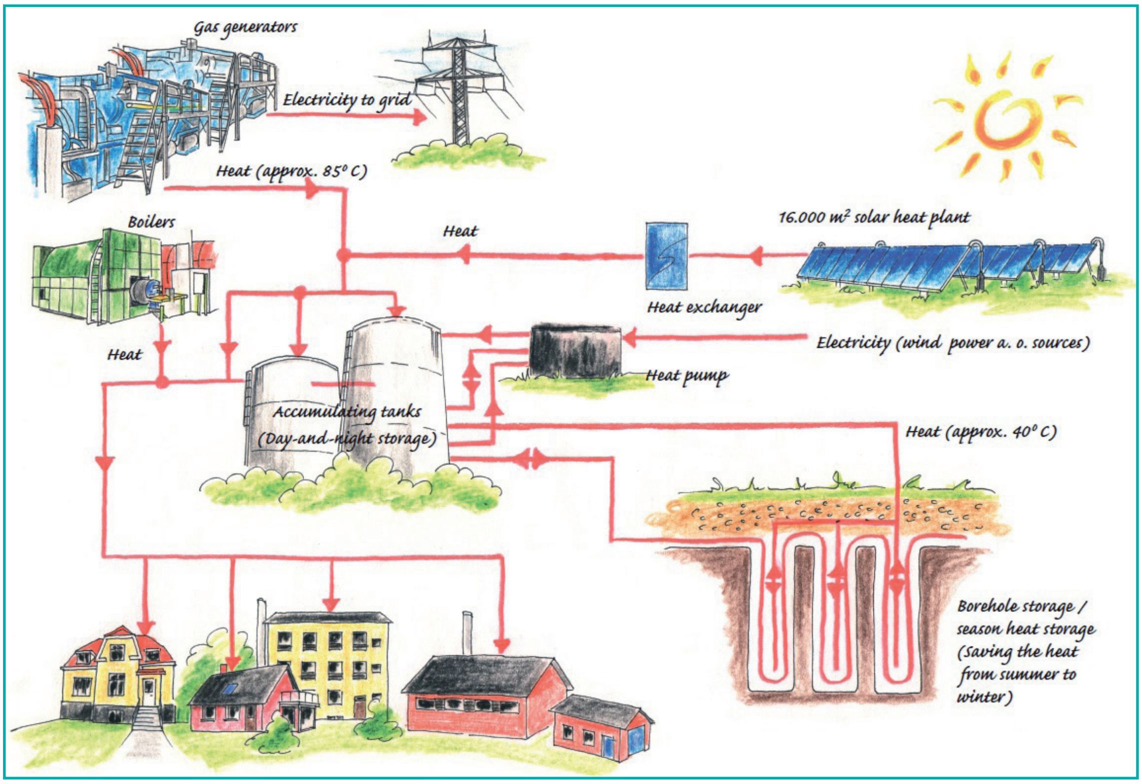

Figure 16 - Concept of an advanced solar thermal district heating system with seasonal heat storage in combination with smart electrical solutions. Source: Brædstrup District Heating Company

3.2.2 DEVELOPMENT OBJECTIVES

Thanks to enhanced and well-targeted R&D activities, the following objectives can be achieved in the non-residential solar thermal heating sector.

New highly efficient medium and high temperature collectors will be available at low costs and with high reliability. Due to the high demand for process heat in the medium and high temperature range, it is anticipated that these improved collectors will help towards exploiting this market segment.

Turn-key solar thermal process heat systems will be available for main types of applications. Each industry sector has its own demand profile and it is conceivable that turn-key solar thermal systems, which can easily be adapted to the factory site, will be available for many applications at competitive costs. With less time spent on design, these systems could become much more widespread.

Solar thermal based poly-generation systems (combining electricity, heat, cold, and if needed seawater desalination) will be developed to increase the market potential of solar thermal process heat and contribute to increased efficiency in the overall energy system.

Solar thermal process heat systems tailored to the demand of developing and emerging countries will be available. In these countries, the solar insolation is often very high, but solar process heat systems must be simple, robust and cheap to be competitive. Therefore dedicated solutions must be found and, in addition, socio-economic and cultural factors must be taken into account by developing and transferring technology.

Adapted components and concepts for large-scale solar thermal systems, especially for district heating systems, will be available with increased efficiency, improved reliability, higher durability and reduced costs.

3.2.3 MAIN R&D CHALLENGES

Theme 1: Developing dedicated medium and high temperature collectors

The use of solar thermal energy in the medium and high temperature range (95°C – 400°C) requires the availability of cost-effective and dedicated highly efficient collectors. R&D is needed to identify and integrate high temperature-resistant materials, to develop new collector designs and cost-effective construction techniques. New designs may evolve either by improving low-temperature flat-plate and evacuated tube collectors: e.g. through better insulation or noble gas atmospheres; or by developing specific concentrating collectors using light-weight, stable and highly performing dirt-proof or self-cleaning reflectors resistant to degradation through mechanical cleaning and weathering. Moreover, cost-effective fixing systems are required for specific installation and maintenance of large-scale applications. The hydraulics for these collectors, which are mainly used in large collector fields, must be optimized to allow uniform flow distribution and low pumping power. Additionally, specific testing procedures, standards and certification schemes must be elaborated as well as accelerated ageing tests for these medium and high temperature collectors and materials.

Theme 2: Developing cost competitive turn-key solar thermal process heat systems

R&D is needed to identify and optimize relevant industrial processes to make them more suitable for solar thermal systems, e.g. through conversion from steam-based to water-based supply systems and adaptation of machinery and heat exchangers for solar input. In addition, novel integration schemes for solar generated heat on process and supply level of industrial plants must be developed and solar thermal system designs optimized accordingly. On the supply level, direct steam generation by medium-temperature collectors is needed for industrial steam networks which cannot be adapted, since high temperatures are needed for these processes.

Based on the development, realization, monitoring and analysis of a series of large-scale demonstration systems for different industry sectors and applications, regions and climates; turn-key solar thermal process heat systems for specific sectors must be developed which can be easily adapted to a specific manufacturing plant. Furthermore, harmonized monitoring, metering, and evaluation standards must be evolved to provide performance guarantees and to facilitate incentive schemes such as a thermal feed-in tariff. Moreover, new financial models, such as contracting or solar thermal ESCOs, are essential.

Theme 3: Developing solar thermal energy based poly-generation systems

The share of renewable energies in energy systems will continuously grow worldwide. This requires constant improvements in the efficiency of energy systems. Solar thermal energy based poly-generation systems, which are combining the generation of electricity with heat and cold, can achieve very high efficiency by using the energy in an exergetically optimal way. Heat with different temperatures can be produced and used for different industrial processes or for seawater desalination. R&D is needed to identify optimal system configurations to develop application adapted components and operation, and control strategies.

Theme 4: Developing advanced large-scale solar thermal district heating systems

R&D is needed in system technology towards developing advanced district heating systems which are able to deal with a combination of centralized and decentralized hybrid heat sources such as solar thermal, heat pumps, biomass CHP plants and waste heat. In addition, the integration of thermal energy storage must be optimized. Smart thermal metering and load management systems are called for to combine solar district heating system with the electrical grid. Such smart thermal-electrical grids will meet the load balancing needs of combined heat and power production in a liberal market for electricity. With regard to components, decentralized cooling and air-conditioning units for the integration in district heating systems must be developed, as well as cost-optimized long-term heat storage technologies (see chapter 3.4 and 3.6). Integration and standardization of thermal components are required to the extent that they can all be considered as standardized hydraulic 'building blocks'.

As a non-technical task the development of new business models is crucial, effectively addressing the operational and legal issues of smart district heating, and taking into account the whole supply chain involved in district heating. Finally, large-scale demonstration systems are required to show that advanced solar district heating systems can provide a solution for the load balancing aspects and new requirements of thermal-electrical integrated smart grids.

Figure 17 - 6000 m3 seasonal water storage for a solar district heating system in Munich, Germany, before being completely covered with soil. Source: ZAE

3.2.4 R&D PRIORITIES

R&D priorities for non-residential solar thermal applications are:

up to 2020	beyond 2020
Development of : • medium and high temperature collectors for industrial applications and district heating networks • optimized low-cost large-scale solar collector arrays for uniform flow distribution and low pumping power • standards and certification schemes as well as accelerated ageing tests for medium-temperature collectors and collector systems • classification of suitable industrial processes and applications for solar heating systems • novel integration schemes for solar generated low temperature heat as well as steam in industrial processes • planning guidelines and tools for solar thermal in industrial processes • innovative system design and design developing tools for an optimized use of solar thermal heat in industrial applications (including hydraulics and control strategies) • poly-generation concepts, systems, operation strategies, and adapted components • adapted process heat system technology for developing and emerging countries • system technology for optimized operation of solar thermal district heating systems with seasonal storage • concepts and technologies to reduce the temperature of the return flow in solar thermal district heating systems • technical concepts and business models to integrate decentralized solar thermal systems into heating grids • technical concepts and business models for thermo-electrical smart grids with integrated solar thermal systems Demonstration of : • solar thermal process heat systems with improved system design for different industry sectors and applications • advanced solar thermal district heating systems • the integration of decentralized cooling and air-conditioning systems into solar thermal district heating systems • advanced concepts of solar thermal energy based polygeneration systems (combinations of power, heat, cold and desalination) with improved efficiency • industrial process heat systems adapted to the specific needs of emerging countries	Development of : • system design with increased solar thermal fraction in smart heating grids • large-scale systems for low and medium temperature applications in industry • new solar applications like solar chemistry for the producing industry • further improved and cost-reduced solar thermal energy based polygeneration systems (combinations of power, heat, cold and desalination)

3.3 SOLAR COOLING AND REFRIGERATION SYSTEMS

Since the cooling demand usually increases with solar radiation intensity, thermal driven cooling systems, including air conditioning and refrigeration systems run by solar thermal energy, have a huge potential in the constantly growing cooling and refrigeration market worldwide.

3.3.1 STATE-OF-THE-ART

Worldwide, most cooling and refrigeration systems are powered by electricity. Due to growing cooling and refrigeration demand, peak-load problems in the electricity grid in countries with high cooling load are forever increasing. Thermally driven cooling technologies represent promising alternatives and are set to play a key role in the efficient conversion of energy in the field of building air-conditioning and refrigeration. Today, these technologies are used mainly combined with waste heat, district heat or co-generation plants. But thermally driven cooling cycles can also run with solar thermal energy. In climates where cooling is not required all year round, solar thermal driven cooling systems can also be used for space heating or domestic hot water preparation during periods without cooling demand.

Over the last two decades, around one thousand solar thermal assisted cooling systems have been installed worldwide, mostly in Europe, within the framework of research and demonstration programmes. A few years ago, market development and commercialization started in the residential sector in Mediterranean countries (e.g. Spain) and in the office building sector in Asia (India, Singapore, China). The analysis of the first commercial market development phase highlights a substantial potential to accelerate this development with further R&D work.

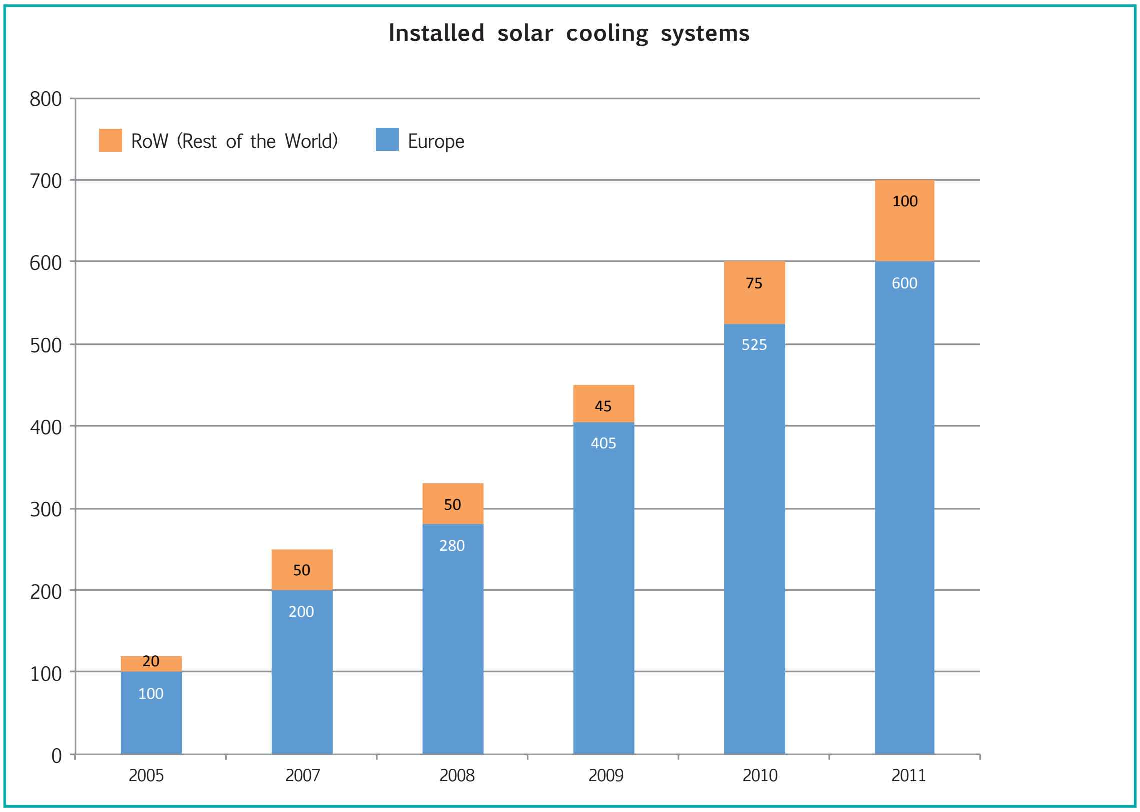

Figure 18 - Total number of estimated solar cooling systems installed worldwide.
Sources: Solem Consulting / Climasol, Fraunhofer ISE, Rococo, Tecsol

Up to now, solar thermal driven air-conditioning and refrigeration systems have high capital costs due to the number of system components, i.e. cooling equipment, solar collectors and heat storage appliances, and have not been cost-competitive with conventional electrically-driven cooling systems. Thermally driven cooling cycles employ refrigerants with no ozone depleting potential and no, or very small, global warming potential. Most systems use water as refrigerant.

So far, mainly pilot plants and a few commercial plants have been in operation, limited practical experience and know-how is one of the major barriers to widespread installation of solar air-conditioning and refrigeration systems. Only a small number of professionals are well informed on both solar thermal and air-conditioning in buildings. Due to this limited experience with solar cooling and refrigeration systems, measures are needed to encourage the dissemination of existing know-how and improve system quality.

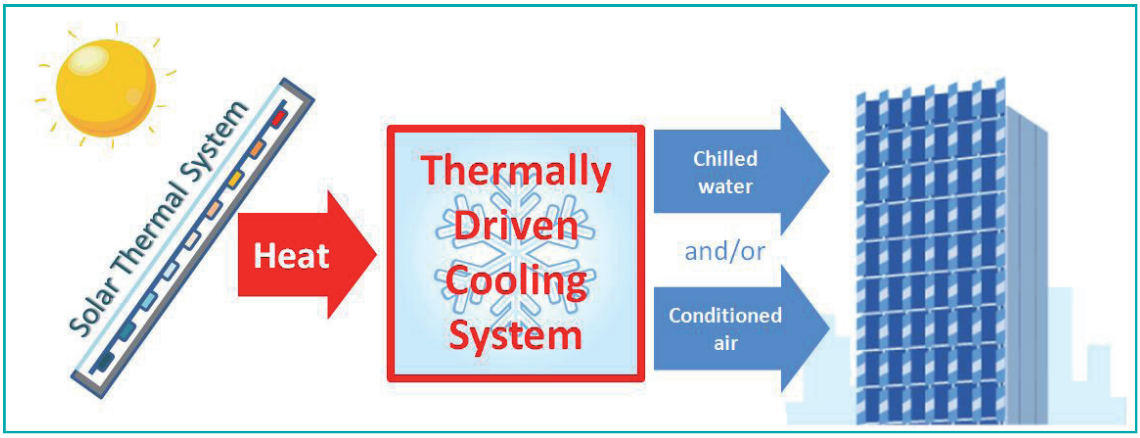

Figure 19 - Simplified illustration of a solar cooling system, which can provide cooling by chilled water or by delivering conditioned air.

Figure 20 - Solar collector field and cooling tower of a small solar cooling system. Source: Tecsol

3.3.2 DEVELOPMENT OBJECTIVES

Solar thermal cooling and refrigeration is a promising technology, which can significantly contribute to meet the growing cooling and refrigerating demand in a sustainable way. The following objectives can be reached thanks to R&D activities.

Cost-competitive solar thermal air-conditioning and refrigeration systems will be available. Since heat driven cooling technology is still in its infancy and relatively unknown in comparison with mechanical (i.e. electrical) vapour compression, the costs of solar thermal driven air-conditioning and refrigeration systems will be greatly reduced through technological improvements in basic materials, component design and system technology.

New absorption and adsorption chillers with improved performance will be used. The performance of solar air conditioning and refrigeration systems will be increased considerably due to higher temperature of heat rejection in new absorption and adsorption chillers, as well as new desiccant and evaporative cooling concepts (solid and liquid desiccant sorption systems). With the availability of high performance medium temperature collectors, multi stage chillers can be used with significantly improved COP.

Solar thermal cooling systems components will be integrated into the building at the time of construction. At present, solar cooling systems are added to a building after it has been built. In future, systems will increasingly be incorporated into buildings. Solar collectors, heat sinks and heat stores can already be fully integrated into buildings at the time of construction to reduce costs.

Industrial refrigeration processes will be adapted to enhance the use of solar driven refrigeration systems. The cold supply for industrial processes is nowadays mostly provided at temperatures far below levels required by the process. Optimization of these cooling systems will greatly reduce the need for this “over-cooling” and greatly enhance the potential for integration of solar driven refrigeration systems.

The quality and reliability of solar cooling and refrigeration systems will be enhanced by a compact system design, the development of design guidelines and tools, stagnation-proof collector and system design, and system controller units, which guarantee an energy efficient operation. Furthermore, advanced and energy efficient cooling towers for dry and wet heat rejection will increase the reliability as well. Advanced heat rejection technology will be developed to reduce the auxiliary electricity needed to reject the waste heat of the thermally driven cooling device and lower the operation cost of the cooling system.

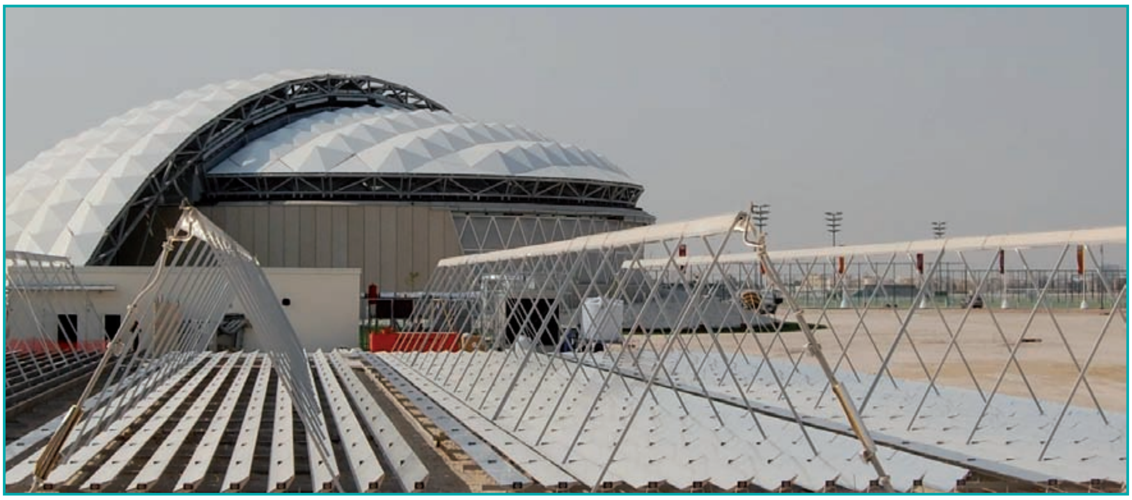

Figure 21 - Solar cooling system with Fresnel concentrator collectors for the showcase football stadium in Doha, Qatar. Source: Industrial Solar

3.3.3 MAIN R&D CHALLENGES

Theme 1: Improving solar thermal cooling systems components

New, highly-porous sorption materials, especially using adsorption chemistry and, possibly, ionic liquids must be developed to improve the performance of thermally-driven cooling machines. In addition, new, highly flexible cooling cycles (high temperature lift; double, triple stage and new open sorption, including hybrid sorption-compression, advanced ejector cycles) must be developed to allow solar operation under variable temperature and power conditions, as well as cooled open solid sorption cycles with a high dehumidification potential for warm and humid climates.

Novel heat exchanger concepts including micro-fluid systems must be developed for compact, high efficient heat transfer in the sorption and desorption regimes; as well as sorption heat transfer matrices, such as metal foams and nano-coated surfaces in heat exchangers for reduced pressure losses during fluid flow. This will result in highly compact machines and very small systems with the capacity to cool a single room and which may also be used in the automotive and transport sector.

Component development will focus on highly-efficient solar thermal collectors, either with a direct hydraulic connection to the chiller, or even with the generator integrated into the collector itself. New materials for cold storage at different temperature levels will be developed to reach high cold storage density, as well as new system controllers to improve system performance with the target of an overall electrical COP on system level above 10. Finally, new heat rejection options will be assessed, using the air or ground as a heat sink. Such heat rejection devices must be adjusted to the various sizes and temperature levels of thermally-driven cooling cycles, and need to focus on low water and power consumption.

Theme 2: Improving performance, integration and costs of solar cooling systems

Research on system level must concentrate on reducing parasitic energy consumption through the integration of highly efficient components (e.g. variable speed pumps, specific heat rejection units) and optimized control strategies. This requires the development of advanced simulation tools for system modelling from the molecular to the system scale. Furthermore, performance analysis tools, such as exergy analysis, lifecycle analysis and comparison methodologies to assess new concepts, will be developed. Hydraulic concepts will be elaborated to enhance the cost-performance relation, develop design guidelines and proven operational and maintenance concepts for overall systems.

Solar cooling systems must be adapted to, and optimized for, industrial process and large-scale solar refrigeration plants, as well as district heating systems with decentralized cooling units. New commissioning procedures, guidelines and standards for components and overall systems must be developed, and appropriate training materials provided for installers and engineers (see also 3.8 and 3.9, respectively).

Figure 22 - Absorption chiller of a small solar cooling system. Source: Pink

3.3.4 R&D PRIORITIES

R&D priorities for solar thermal cooling and refrigeration technologies are:

up to 2020	beyond 2020
Development of : • optimized sorption materials (ionic liquids, adsorption materials) • new double- and triple effect cycles with high efficiency • improved heat exchangers (sorption coated) • optimized controllers for the solar cooling system (leading to system COPel > 10) • new simulation tools for detailed thermodynamic system analysis • user-friendly design tools for cooling and refrigeration systems • new high efficient heat rejection units for small / medium scale heat pumps / chillers • standardized plug-and-function small and medium sized solar thermal cooling kits • single-package systems cost halved by 2020 (ready installed costs) • highly efficient auxiliary components (pumps, fans, control units) to reduce the parasitic energy consumption • hydraulic concepts to improve cost-performance relation, design guidelines and proven operational and maintenance concepts for overall systems • concepts to integrate solar thermal cooling systems in smart cooling grids • appropriate training materials for installers and engineers • highly integrated systems for cooling, heating, hot water, process heat Long-term field-testing of : • solar thermal cooling systems in different Southern European and Mediterranean climates • solar driven refrigeration using double and triple effect cooling cycles with different types of solar thermal collectors (non-tracking and tracking) in sunny regions	Development of : • further improved sorption materials (ionic liquids, adsorption materials) • new generation of heat exchanger concepts (micro-fluid systems for compact, highly efficient heat exchangers in the sorption and desorption regimes) • cold storage with high storage density • cooling machines with new cooling cycles (high temperature lift; double, triple stage and novel open sorption, including hybrid sorption-compression, advanced ejector cycles) • highly efficient solar thermal collectors, specifically adapted for solar cooling systems • highly compact solar cooling units with the capacity to cool a single room Testing and evaluation of : • new generation of highly compact solar thermal cooling systems • advanced large-scale poly-generation systems which integrate cooling, process heat and power generation, e.g. in industrial applications in Mediterranean countries

3.4 SOLAR THERMAL COLLECTORS

Solar thermal collectors convert solar radiation into useful heat. A number of technologies, including unglazed, flat-plate, evacuated tube and concentrating collectors, are available on the market to provide the temperatures and efficiency needed by different applications. The three distinct temperature ranges in which solar thermal collectors operate and their corresponding applications and technologies are defined in Table 3.1.

Table 3.1 – Collector temperature ranges, applications and technologies

Temperature needed by the application	Type of application	Collector technologies used
Low temperature 20°C – 95°C	Swimming pools, domestic hot water heating, space heating, district heating, solar cooling and low temperature process heat	Unglazed, flat plate, evacuated tube and CPC concentrator collectors
Medium temperature 95°C – 250°C	Process heat, desalination, water treatment, high efficiency solar cooling, district heating and cooling	High efficient vacuum insulated flat plate, evacuated tube, CPC and other low concentrating, linear Fresnel and parabolic trough collectors
High temperature > 250°C	High temperature process heat and electric power via thermal cycles	Parabolic troughs and linear Fresnel collectors, solar dishes and solar towers

In this document collectors for temperatures up to 400°C for heat use applications will be considered as electrical generation which is outside the ESTTP remit.

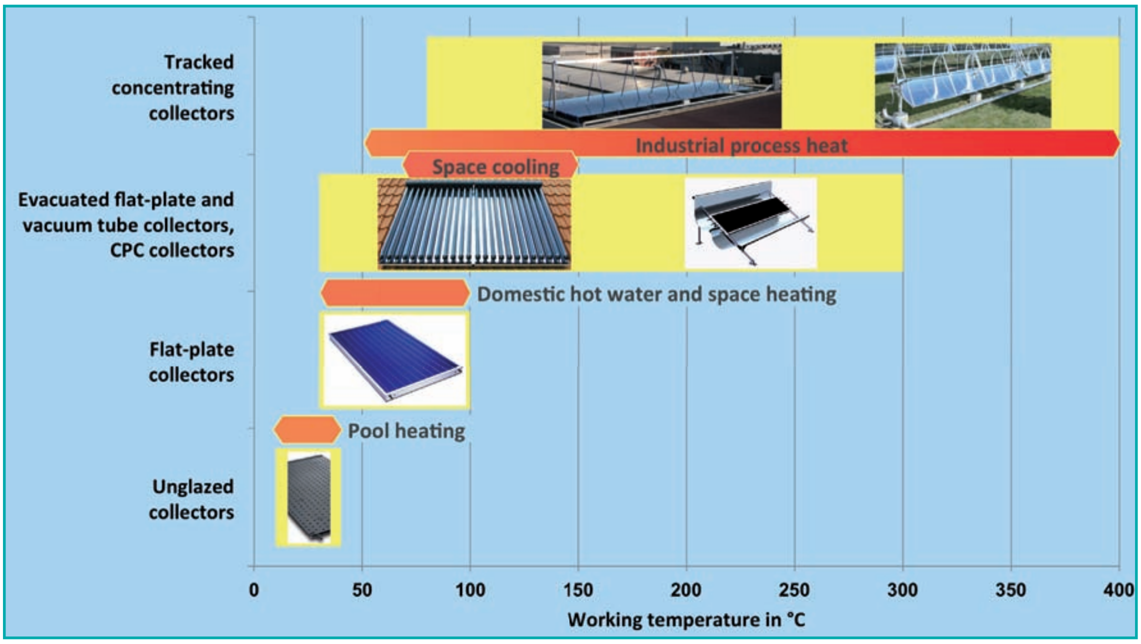

Figure 23 - Working temperature of different types of solar thermal collectors (pictures from Industrial Solar, Roth Werke, Solitem, Solvis, SRB energy, Wagner & Co)

3.4.1 STATE-OF-THE-ART

Collectors generally include an absorber to convert the solar radiation into heat and piping to capture the solar heat. In Central and Northern Europe the absorber is usually coated with spectrally selective coating with absorbance values of 95% for solar radiation and infrared radiation emittance below 10%. Glazed collectors consist of a transparent cover, insulation, a structural mounting frame and, sometimes, reflectors.

In flat plate collectors the absorbing layer is usually applied to a metal plate of copper or aluminium welded to the piping structure, usually in copper. Several R&D institutes and solar companies are working on the introduction of plastics in collectors, to reduce costs. In Central and Northern Europe, high transparent low-iron glass is used as a cover, sometimes coated with anti-reflective coating to further increase the efficiency. In Southern Europe, glass for windows is occasionally used in cheap collectors. Rockwool and melamine foam are typical flat plate collector insulation materials. R&D work on aerogels, high vacuum insulation and transparent honeycomb materials is ongoing.

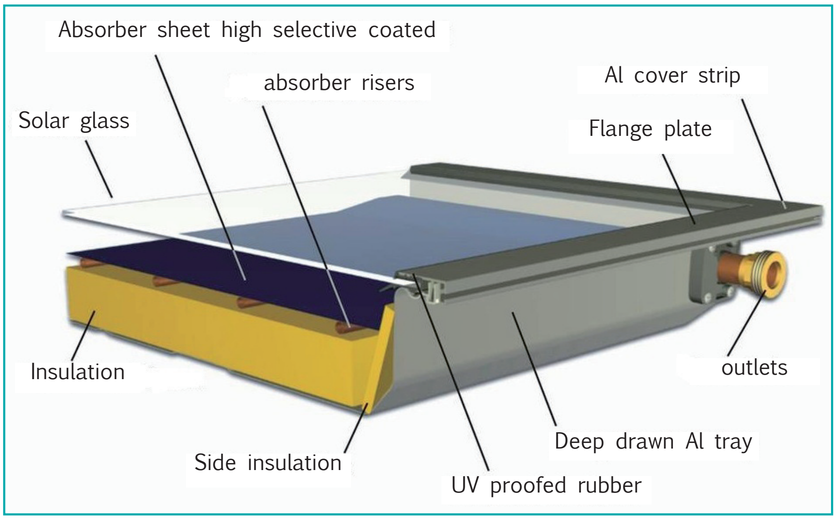

Figure 24 - Exploded view of a flat plate collector. Source: GREENoneTEC

There are several types of evacuated tube collectors available on the market. The main product is the so called 'Sidney type vacuum tube', consisting of two glass layers with a vacuum layer in between. A spectrally selective absorber layer is fitted on the outer side of the inner tube, which means that it is safe in the evacuated space. The advantage of these types of tube is that only glass-glass connections are necessary to enclose the vacuum. In Europe a metal heat exchanger is inserted in the inner glass tube to transfer the heat produced. The simple systems, mainly used in China, where the inner tubes are filled with water and directly connected to the storage tank above the collector using the thermosiphon effect, are not used in Europe. Other types of evacuated tubes have a single glass tube with a metal absorber located within the vacuum. The heat is transferred to the header via direct flow of the heat transfer fluid through the tube with pipes welded to the absorber, or via heat pipes connected to the absorber and the header. In both cases a metal-glass connection is necessary, which must be of high quality to ensure a long lifespan of the vacuum.

Some evacuated tube collectors use compound parabolic concentrator (CPC) reflectors behind the tubes, usually made of aluminium. Advanced reflectors manufactured from coated plastics are under development.

Figure 25 - State of the Art European evacuated tube collector, using high temperature composites as a manifold fluid
Source: Kingspan

Since collector efficiency is improving, potentially higher stagnation temperatures of up to 250°C, even for non-concentrating glazed flat plate collectors, can be reached. Therefore, high temperature-resistant components, insulation and heat transfer fluids, or temperature limitation mechanisms are required. Today, typical systems in Europe use a water-glycol mixture which prevents freezing depending on the mixture concentration and which provides high temperature resistance long-term of up to 170°C and short-term of up to 200°C. Frost-protected solar systems without glycol have also entered the market. Thermal diode devices for stagnation protection have been marketed since the 1990s, but these are only available for a small number of evacuated tube collector types.

Advanced medium temperature collectors are under development owing to the evolution of existing technologies including advanced flat plate and evacuated tube collectors, multi-cover optics, and low concentration tracking linear parabolic systems and CPC collectors. Recent developments of high vacuum flat-plate collectors (vacuum below 10-3 mbar) show high efficiency at temperatures between 100 and 200°C.

Tracking collectors provide higher temperatures with higher efficiency; however, they can only use direct sunlight. Therefore, they will be mostly used in Southern Europe where the remaining diffuse part of the radiation is much lower than in Central or Northern Europe. There are parabolic trough and linear Fresnel concentrators on the market. Typical reflectors are made of aluminium, polymer or glass sandwich structures. Linear Fresnel collectors use a faceted reflector with a big focal length allowing the use of highly reliable flat glass mirrors. Compared with parabolic troughs, linear Fresnel collectors have a bigger aperture area per receiver unit, lower wind load, and higher ground usage ratios. This is especially interesting for rooftop installations and can compensate for the reduced optical efficiency due to the non-ideal reflector.

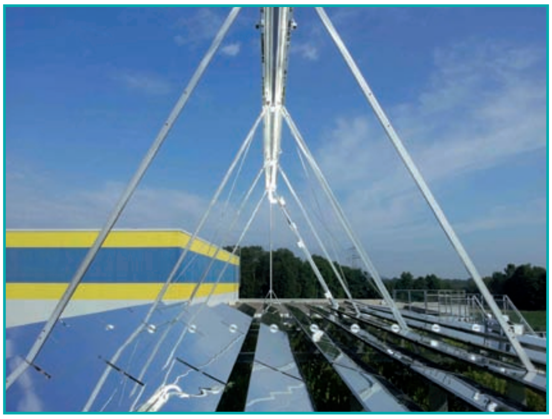

Figure 26 - Concentrating linear Fresnel collector. Source: Industrial Solar

Figure 27 - Concentrating parabolic troughs collector. Source: Solitem

Air as heat transfer medium provides specific advantages compared to liquids. Air collectors are used as uncovered façade air collectors for space heating: e.g. in industrial buildings via the supplied air. Glazed air collectors are usually installed to support space heating by preheating the supplied air in residential homes, office buildings and isolated buildings. Hot air is also used for industrial processes and for drying agricultural products or wood for biomass plants.

Synergies can be obtained by combining solar thermal collectors with other technologies. Photovoltaic-thermal (PVT) hybrid collectors produce heat and electricity. Generally, they offer the highest efficiency by converting solar radiation into energy per area. Unglazed PVT collectors combining a PV-module with a heat exchanger, to reduce the temperature of the PV module, are already on the market. They can provide hot water only when combined with a heat pump. Glazed PVT collectors, where the PV-module-absorber-sandwich is built in a collector housing and providing domestic hot water without heat pumps, are under development.

Figure 28 - Non tracking TVP high vacuum flat-plate collector with mirrors which can reach temperatures up to 400 °C. Source: AEE INTEC

3.4.2 DEVELOPMENT OBJECTIVES

There is still great scope for the technological development of solar collectors. The following objectives can be reached thanks to R&D activities.

Improved cost-effectiveness will be achieved through increased efficiency and reduced costs. Efficiency will be improved by about 10% by 2020 whereas costs will be reduced up to 40%. Therefore, by 2020, costs per energy unit produced will decrease by around 50%. This will be achieved with higher performing and/or lower cost materials, designs and manufacturing technologies and processes, as well as with the type of installation and the combination with or the integration into other technologies. To achieve this goal, solar collectors must be better adapted to specific applications, i.e. to the temperature level required, to the kind of installation, including integration into buildings, and to the type and size of the solar system, e.g. large collector units for solar district heating plants.

Simplified installation and improved integration into the building envelope will reduce costs and improve the aesthetics of using solar thermal collectors. By harmonizing the techniques and standards for installing and connecting solar thermal collectors with each other and with other building components such as roof tiles, skylights and façade elements, their installation will become simpler, faster and cheaper. The outcome will be an aesthetically pleasing integration of the collector into both roof and façade. For listed buildings, “invisible” collectors will be developed, made to copy the building elements they are replacing. Concepts for the integration of concentrating solar collectors for medium temperatures up to 250°C into roofs will be developed, especially for daily or seasonal tracking techniques with long lifespan at low investment and maintenance costs.

Improved materials as well as construction and operating concepts will increase the reliability and the long-term performance stability of solar thermal collectors. Since collectors will become an integral part of the building envelope, the collector lifespan must be increased to more than 20 years. This will be achieved with new materials and concepts preventing or limiting collectors’ stagnation and overheating, e.g. by reducing the collector efficiency above a critical temperature.

Dedicated solar thermal collectors for specific temperatures, weather conditions, water quality and application will improve the cost-effectiveness of solar thermal systems. Currently, only a few collector types are used for most applications, as mass production of such typical 2 m2 collector modules means low costs, even if the collector’s characteristics are not ideal for a given application. With the growing demand in today’s niche markets, dedicated collectors for specific applications and framework conditions will become the most cost-effective way to use solar thermal energy.

3.4.3 MAIN R&D CHALLENGES

Theme 1: Increasing collector performance at reduced cost

Improved efficiency and reduced costs are prerequisite for an increased contribution from solar thermal to the EU heat demand. This can be achieved through the development of new or improved collector materials such as transparent covers with anti-reflective coatings for high optical transmission; switchable coatings to reduce the stagnation temperatures; high reflective and low weight materials for reflectors; new absorber materials with low emission coatings; optimized heat transfer; temperature resistant super insulating materials; and alternative high temperature materials like polymers or rubbers for collector parts. Further improvements can be obtained by developing collectors better suited to applications’ requirements with adapted performance, improved integration, PV-thermal technologies, air collectors and dedicated process heat collectors, with either better vacuum or noble gas insulation or improved concentrator geometries and quasi-static, tracking or seasonally adjustable systems. Finally, a continued improvement in the collector manufacturing processes, focussing on mass production of tailored systems and systematic recycling of materials, will lead to further cost reduction of solar thermal collectors. New materials like polymers could also result in new production techniques.

Theme 2: Simplifying and improving collector installation and integration

The installation of solar collectors is a significant part of the value chain and the quality of installation is an important aspect of the user’s acceptance of solar thermal systems. With improved installation concepts, costs can be reduced and the system lifetime reliability increased. This can be achieved through standardized hydraulics connections and plug & function concepts. Novel roof and façade collector fixing techniques must be developed for better roof and façade integration to achieve architectural excellence, to use limited roof space effectively and to assure a high security regarding static requirements.

Theme 3: Increasing reliability and long-term performance stability

R&D is needed to develop and evaluate new materials, coatings, construction and operating methods, towards increased lifespan by reducing ageing effects, and avoiding stagnation and overheating of the collectors. Providing self-cleaning and corrosion-resistant surfaces will inhibit deterioration. To determine accurately the long-term behaviour of collectors in accelerated ageing tests, methods and standards must be developed.

Theme 4: Developing dedicated solar collectors

The attractiveness of solar thermal energy will increase further by adapting solar thermal collectors to the type of application and climate conditions, which means adapting the performance and characteristics to the specific needs and to optimize the collector's cost-effectiveness. Collectors will be earmarked for specific temperatures (including process heat collectors, see 3.3.3), seawater qualified collectors, Photovoltaic-thermal hybrid collectors, air collectors, façade collectors, storage collectors, etc. R&D is needed to maintain performance by using cheaper materials like polymers or nano materials or increase the performance. This can be achieve by using high vacuum or noble gas, ensuring high quality and reliability while reducing costs by adapting materials, as well as integrating and optimizing functionalities such as overheating protection or electricity generation with photovoltaic.

3.4.4 R&D PRIORITIES

R&D priorities for solar thermal collector technologies are:

up to 2020	beyond 2020
Development of : • new surfaces, coatings, materials, collector designs, and manufacturing technologies lead to an increased system performance by 10% and reduced collector costs by 50% • high temperature insulation material • methods to avoid overheating and stagnation by switchable surfaces and materials and other measures to reduce collector efficiency at higher temperatures or by fail-safe heat dissipation techniques • improved mounting structures which reduces the static load at lower costs and higher flexibility • innovative, easy to install hydraulic collector connection technologies for high reliability and reduced installation costs • new concepts for façade integrated collectors including switchable transparency • glazed PV-thermal (PVT) collectors with improved thermal performance and high reliability • new concepts for roof integration of concentrating and tracking collectors • industrial manufacturing concepts for medium temperature process heat collectors • standards for new collector technologies Demonstration of : • pilot projects with new façade integrated collector types • pilot projects with roof integrated medium temperature collectors • large scale district heating, process heating and solar cooling projects with new collector technologies	Development of : • ully building integrated process heat collectors • standardized integration of solar heat into buildings and systems. • high efficient fully façade and roof integrated PVT-collectors with stagnation protection • advanced liquid or gaseous fluids for heat and cold transfer

3.5 THERMAL STORAGE

Since in almost all heat applications there is a mismatch between solar radiation and heat demand profile, usually a thermal storage is needed to make solar thermal energy useable. Depending on the scale of the mismatch and the desired solar fraction, thermal storage is designed to bridge the gap for only a few hours or days, up to some weeks or months. However, to store solar thermal energy means additional investment costs and additional thermal losses, which are increasing with storage size and duration. Therefore, the challenge is to achieve a specific goal, which could be low solar thermal heat costs or high solar fraction, with an optimized system design by optimizing collector size, storage volume and other criteria.

3.5.1 STATE-OF-THE-ART

By nature, solar energy is a fluctuating energy source. Therefore, thermal storage is very important to guarantee a constant supply of solar thermal energy to the consumer or process requiring heat. With improved thermal storage technologies, the opportunities for using solar thermal energy increase dramatically.

Almost all current thermal storage technologies use water or soil as storage material. Water has many advantages and will remain an important storage medium for many applications, especially those for which enough space is available and where temperatures are between 0°C and 100°C. In other application areas, new storage materials and technologies are needed, notably for higher temperatures, longer storage periods or where space is at a premium.

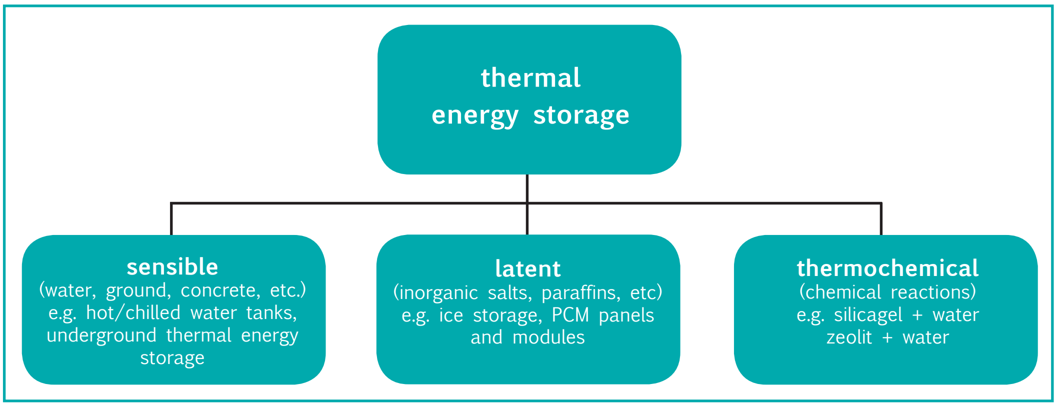

Figure 29 -Thermal energy storage characterisation

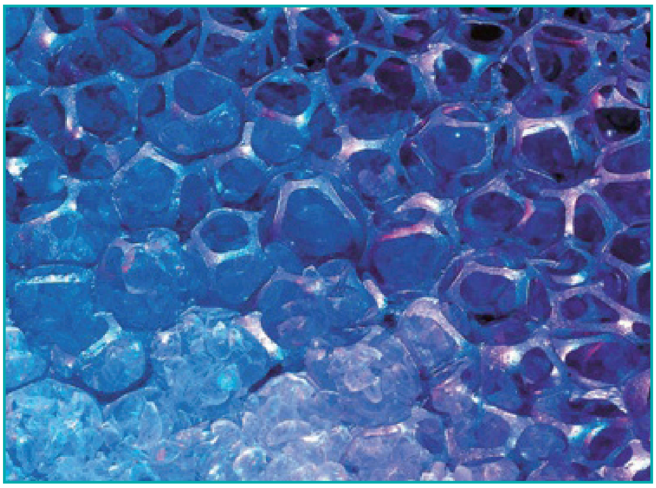

Figure 30 - Metal foam for thermochemical storage.
Source: Fraunhofer ISE

3.5.2 DEVELOPMENT OBJECTIVES

A significant improvement in storage performance can be achieved in three ways: via heat loss reduction, compactness of the storage material and efficiency in the charging and discharging process. There is a huge potential for technological development in very large seasonal heat storages.

Heat losses in thermal storage will be significantly reduced resulting in increased solar fraction. Heat losses from sensible thermal energy storage technologies will be reduced by improved thinner insulating material with higher thermal insulation values and by reducing heat losses at the piping connection points. Heat losses will also be cut by using larger systems with larger storage volumes, e.g. solar thermal district heating systems with seasonal storage, by using better volume to surface area ratio. Storage with intrinsically little or no heat losses using thermochemical storage materials will be developed, facilitating seasonal heat storage.

Compact thermal storage technologies will reduce the storage volume by a factor of eight and lower heat losses significantly. Latent heat storage and thermochemical heat storage will be developed by using well-known storage materials such as phase change materials, zeolites, salt hydrates or composite materials, and by using new materials such as MOFs, AlPOs, SAPOs, etc.[9] to enhance storage performance. These storage technologies will lead to increased solar fraction for space heating, especially in refurbished building, where storage space is limited.

Storage efficiency will be increased by improved storage charging and discharging processes. Improved charging and discharging devices will be developed which do not negatively impact the stratification of sensible thermal storage. For latent and thermochemical storage, new techniques for optimized heat transfer to and from the material will be developed, as most available storage materials have inherent poor heat transfer properties. Heat transfer process improvements will be achieved through the development of new heat exchanger materials or geometries, or by developing new processes for heat and mass transfer in thermochemical storage.

Long lasting, cost-effective seasonal thermal storage for district heating systems will be developed by using improved construction technologies. District heating systems are prerequisite to supply renewable generated heat to densely populated urban areas. Large-scale seasonal thermal storages are essential to achieve a high solar fraction in such systems. Smart cities and industrial estates will use such systems with large-scale storage, to keep the solar heat seasonally from summer to winter and to combine smart electricity with smart heating grids. Due to large storage volumes of thousands of cubic metres the very low surface to volume ratio accounts for low heat losses and low specific building costs.

Figure 31 - Water storage test rig. Source: Fraunhofer ISE

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[9] MOF: Metal-organic framework materials / AlPO: Aluminophosphate / SAPO: silicoaluminophosphate

3.5.3 MAIN R&D CHALLENGES

If thermal storage technologies are to realize their full potential, the following R&D challenges must be met:

Theme 1: Increasing performance of the thermal storage system

The efficiency of the storage and of the entire heating system can be greatly enhanced by high quality insulation of the storage itself, the piping and the connection between storage and piping. R&D is necessary to improve existing and develop new thinner insulation materials with reduced thermal conductivity, including vacuum insulation and aerogels. Low-cost, corrosion-resistant storage tank materials will be developed to increase reliability and reduce costs. Storage system efficiency of water-based storage will be further improved by R&D activities to optimize hydraulics with enhanced temperature stratification, supported by numerical modelling of the flow in such systems. New storage technologies will allow the development of novel and more efficient system configurations. Finally, installation costs will be reduced and reliability enhanced by the development and introduction of standardized fast and fail-safe techniques to connect tanks, pipes and wires.

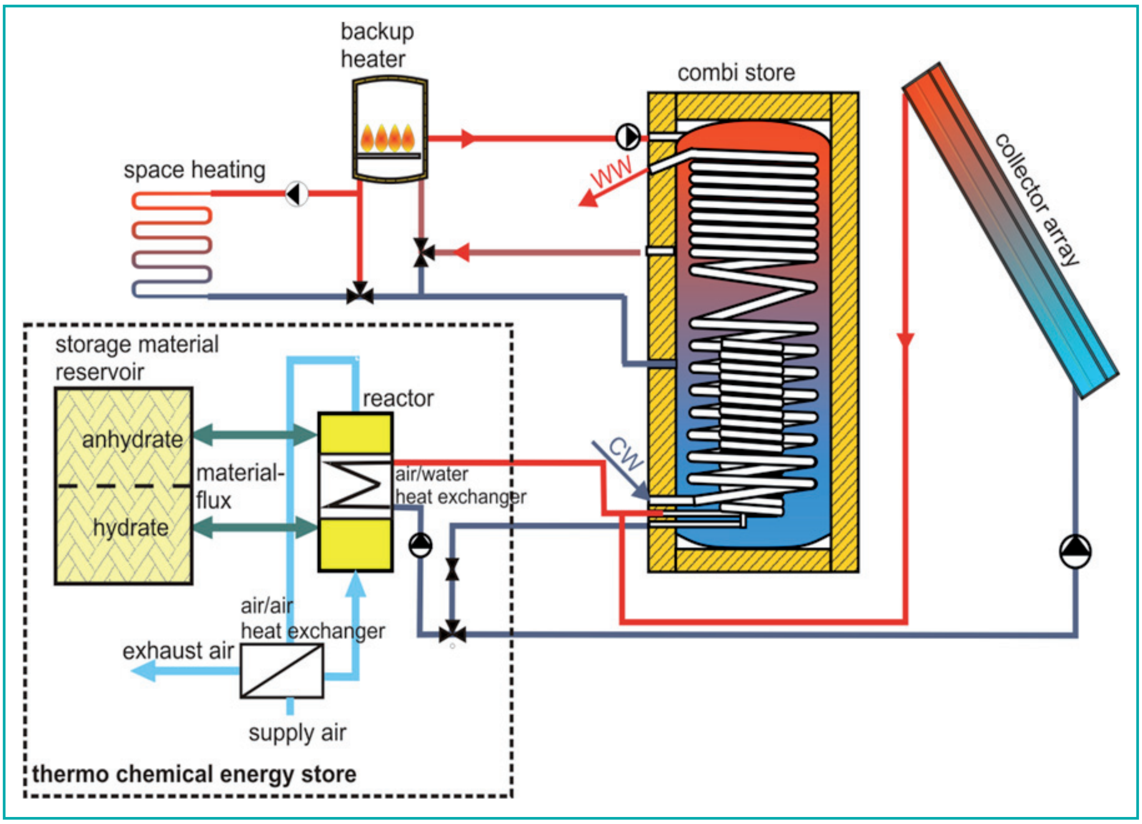

Figure 32 - Lay-out of a compact thermal energy storage system with separate reactor and short-term combi store. Source: ITW

Theme 2: Enhancing storage efficiency by improved heat transfer techniques

Thermal storage efficiency is greatly dependent on the heat transfer from the heat source to the storage and from the storage to the point of heat use. R&D is needed on three levels to improve the heat transfer: by enhancing the heat exchange, the heat transfer media, and the methods of transporting these transfer media. To increase the efficiency of heat exchangers, a better understanding of the interaction between multiphase flow and solid walls is necessary, using laboratory tests and simulations. To enhance the heat transfer media themselves, a combination of active materials with a liquid carrier, such as emulsions or suspensions of encapsulated material, and ionic liquids should be developed and evaluated. In addition, new heat exchangers must be developed for an optimized use of the new heat transfer media. If powders, suspensions, emulsions, and slurries are identified as optimal heat transfer media, a transport concept must be developed, since their transport needs more effort and a sufficiently long lifespan is required.

Theme 3: Increasing storage density by using phase change and thermochemical materials

Storage density can be enhanced by using phase change materials (PCMs). R&D is needed to improve both the amount of latent heat gained at appropriate temperature levels by and the long-term stability of existing PCMs. This requires a better understanding of sub-cooling and phase separation, as well as techniques for combining different PCMs (organic and inorganic). Experimental work is required, supported by numerical models, to select the ideal materials and develop optimized encapsulation processes and emulsion techniques. To enable the use of PCM storage, measurement and control technologies must be developed to identify their charging status, including predictive routines to improve their yield.

Figure 33 - Thermochemical storage prototype testing.
Source: P.Avavian / CEA-INES

The highest thermal storage density can be achieved with thermochemical materials. To make them useable, the relation between structure, composition and thermal storage characteristics, as well as the effects of mixing different materials and of combining active materials with carrier materials, must be evaluated. R&D is required on materials, improved material synthesis methods and production technologies, as well as improved suspension and emulsion techniques. The focus should be on combined production of sorption material and heat transfer surfaces. Numerical models are needed to describe molecular and crystalline interactions.

Similarly, compact, loss-free thermochemical storages require efficient charging and discharging reactor technologies. Two-phase reactors with optimized heat and mass transfer and micro-reactor systems must be evaluated and developed as well as hydrate powder, membrane and suspension reactors. It is vital to explore the reaction catalysis and the effects of catalysts on thermochemical processes. Finally, the reactors must be integrated in the thermal storage and the solar thermal system with enhanced charging and discharging processes and heat transfer techniques.

Theme 4: Developing long-lasting, cost-effective large scale seasonal thermal storage

Several pilot seasonal thermal storages have been built in Europe, but there is still a huge potential for reducing costs and increase both efficiency and lifetime of the storages, which are crucial to achieve high solar fraction in district heating systems. R&D is needed to develop innovative storage construction techniques that can ensure a high level of storage heat insulation for over 40 years, even in water-logged soil, since the storage often has to be, or at least partially, buried in the ground. New low-cost materials for water vapour tightness, that can withstand combined thermal and pressure stress for water storage above 100°C, must be developed as well as multi-functional large heat storages for the combination of solar heat with waste heat from cogeneration, waste incineration or biomass burning.

3.5.4 R&D PRIORITIES

R&D priorities for thermal storage technologies are:

up to 2020	beyond 2020
Development of : • cost-effective water storages with increased efficiency, improved insulation and simplified design • improved low-cost insulation materials and techniques with lower heat conductivity • improved heat transfer and transport techniques using emulsions, suspensions, and slurries • low-cost and stable phase change materials for thermal storages • optimized thermochemical materials, composites and reaction processes, including numerical simulation techniques • novel thermochemical storage technologies with an effective storage density of more than 300 kWh/m3 • standards for the measurements of the performance of phase change and thermochemical materials • new construction techniques for long-lasting, cost-effective large-scale seasonal thermal storages • new concepts to integrate existing storage volumes, e.g. in the industry, in solar thermal systems Demonstration of : • large-scale seasonal thermal storages with new construction techniques	Development of : • system design with increased solar thermal fraction in smart heating grids • large-scale systems for low and medium temperature applications in industry • new solar applications like solar chemistry for the producing industry • further improved and cost-reduced solar thermal energy based polygeneration systems (combinations of power, heat, cold and desalination)

3.6 SYSTEM CONTROL AND PERFORMANCE ASSESSMENT

Over the next decade, solar thermal systems will become increasingly integrated into heating, ventilation and air conditioning systems (HVAC) of buildings, these ‘smart’ systems will incorporate a lot of new functionalities. At the same time, users and installers will expect a simpler interaction with technology, as well as greater transparency on the performance and operating efficiency of solar thermal systems. This requires major advancements in monitoring, controlling, performance analysis, remote maintenance, output control, and certification of solar thermal systems.

3.6.1 STATE-OF-THE-ART

Currently, control units installed with forced circulation solar thermal systems usually control the system by measuring collector outlet and storage temperatures, providing some basic monitoring features. Sometimes, the flow rate in the collector circuit is measured as well for control purposes and to calculate the energy yield provided by the collector field. To further optimize the system performance, additional information is needed, i.e. pressure in the hydraulic circuits, radiation intensity, temperature stratification in the storage and the expected heat demand profile and characteristics. Advanced controllers include capabilities related to remote maintenance and metering for billing.

However, the lack of data about the status of the system, the solar radiation and the heat demand as well as of advanced control algorithms and of harmonization with the control strategy of the entire HVAC system, remains an obstacle for further improvements of solar performance. Improved monitoring and advanced control algorithms can also relate to performance validation, remote performance control and maintenance services. Furthermore, there is still room for improvement in control units regarding cost-efficiency, fail-safe installation quality, user friendliness and operation reliability.

Figure 34 - Solar thermal control unit. Source: Resol,

3.6.2 DEVELOPMENT OBJECTIVES

Novel sensors will increase the performance of solar thermal systems by enabling control units to identify in detail the system operating status. Transparency on system performance, as well as operating status and detection of possible failures are crucial to improve the cost-effectiveness and reliability of solar thermal systems as well as investors’ acceptance. Novel, cost-effective and durable sensors will be developed to provide the information needed and will help to prevent sub-optimal system performance and unnoticed system failures.

Increase the overall system performance by integration of the solar thermal controller into the HVAC system control unit. Optimal performance of the solar thermal subsystem does not guarantee that the entire HVAC system is performing well. Therefore, solar thermal control units will be integrated into the

HVAC control systems, which will control the 'smart building' of the future. The solar thermal control strategies will focus on minimizing the energy consumption, energy costs and CO2-emissions of the entire HVAC system. This concept will be implemented from a single DHW system coupled in series with a gas boiler up to a large solar thermal district heating and cooling system.

The optimal performance of the solar thermal and entire HVAC system in 'smart buildings' and 'smart districts' will be achieved by implementing advanced control algorithms taking into account weather and load forecast data. Innovative controls will take dynamic prices of backup-up energy into account for their control strategy. Performance monitoring and determination of solar gains as a basis for solar incentive tariffs or guaranteed solar results, as well as fault detection by means of online analysis, will also be implemented.

3.6.3 MAIN R&D CHALLENGES

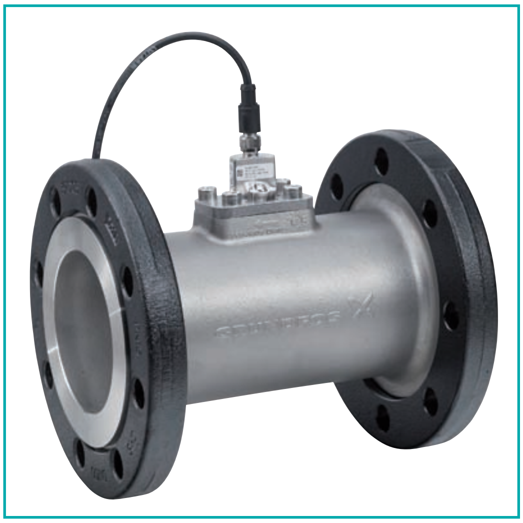

Figure 35 - Vortex flow sensor for heat and cold, for flows between 0,3 - 240 m³
Source: Grundfos

Theme 1: Developing novel, cost-effective and reliable sensors

Today, most of the sensors which could be used for solar thermal systems are relatively expensive, and not as reliable as they should be for operational conditions and the expected lifetime of solar thermal systems. R&D is required to develop novel sensors, which are cost-effective, highly reliable, fast reacting and intelligent. They should measure radiation intensity, heat flow, fluid flow, temperatures and pressure in the collectors, storage, piping and in all other components of the solar thermal system. Both wireless technology and intelligent bus technology are required for communication. Sensor development is also needed to provide compact and cheap meteorological stations, and technology on virtual sensors for estimation of process conditions with lower costs.

Theme 2: Improving communication and integration of solar control units

To improve the performance of the solar and the entire HVAC system, solar control strategies must take into consideration inputs from all parts of the solar and the entire HVAC system. R&D is needed to advance the integration of solar within HVAC control strategies and systems on different levels. Master-slave structures may be installed between the main control system of the building (or the district heating network) and the control unit of the solar system. Strategic operation decisions could be governed by the master control unit, and the solar control unit could aim to reach target operation conditions. This integration requires special attention with regard to standard protocols and developments on general management systems. Alternatively, a total integration strategy may be developed, where just one central unit controls the whole HVAC equipment. This requires the development of communication standards in HVAC systems in general.

Theme 3: Developing and implementing advanced control algorithms

To adjust the operation of solar thermal systems to meet expected weather conditions and user behaviour is the final step to optimize the system performance. R&D is required to develop self-learning and prediction strategies, as well as automated fault detection and self-diagnostics. The underpinning core development is the development of condensed dynamic simulation models with the capacity of self-parameterization based on real operating data. Since the size and computing capacity of local controllers is limited, meta-models are needed to be able to run on relatively simple devices. A similar optimization must be performed for local data logging, analysis, and feedback. This advanced algorithms and models should take all system components into account and should be able to optimize the entire system performance.

3.6.4 R&D PRIORITIES

R&D priorities for system control and performance assessment are:

up to 2020	beyond 2020
Development of : • novel low-cost, long lasting and intelligent sensors • advanced self-learning and self-adapting control and monitoring strategies for solar thermal systems • partly or entirely integrated solar control and monitoring functions into the control unit of the HVAC system by using modern ICT concepts and technologies • new human-machine-interface techniques to ease the setting and operation of the control units by the user significantly • Improved control units enabling solar thermal “plug and function” systems • monitoring concepts and tools to guarantee a well functioning solar system • electrical interface standards for sensors and actuators of the control system • standardized test methods and assessment procedures for controller-dependent behaviour of system components • robust and flexible communication protocols • low cost and robust control and performance monitoring system	Development of : • intelligent sensors fully integrated in all components of the solar and HVAC system • fully integrated control systems for ‘smart buildings’ and ‘smart districts’, which optimize the solar, HVAC and all other technical supply and monitoring system by using advanced ICT concepts and technologies

3.7 STANDARDS AND MEASURES FOR QUALITY ASSURANCE

Standards and measures for quality assurance related to solar thermal systems and components are crucial to develop the technology and user acceptance.

3.7.1 STATE-OF-THE-ART

Several standards applicable to solar thermal systems and components already exist, both at European and international level. The most relevant European standards are the standard series EN 12975 for to solar thermal collectors, EN 12976 for factory-made systems and EN 12977 for to custom-built systems. Quality should be assured by certification schemes for products, systems, as well as planning and installation processes. In Europe, the Solar Keymark was created for the certification of solar collectors, stores and solar thermal systems. Solar Keymark certification is voluntary and based on the European standards mentioned above. Over 90 % of collectors sold in Europe are labelled with Solar Keymark[10], since it is required in most of the European countries to benefit from incentives. A global certification scheme for solar thermal products does not yet exist.

Individual certification schemes for installers are already in place in 14 member states of the European Union (status at January 2012). According to the European RES Directive (Directive 2009/28/EC on the promotion of the use of energy from renewable sources) member states must provide such schemes by 31 December 2012.

3.7.2 DEVELOPMENT OBJECTIVES

Standards and quality assurance measures will be fully implemented to support a sustainable solar thermal market deployment. These instruments will cover all relevant technology areas and aspects; they will be based on the development of existing and the elaboration of new product standards and certification schemes. Standards for solar thermal products and systems determining thermal performance as well as durability and reliability of key components and systems should be developed. Europe should continue to develop and implement standards for new and innovative solar thermal products first at European level and upgrade these to international standards in a second phase, as has been the case up to now.

Simplified solar thermal performance calculations will be integrated in other standards. The appropriate integration of solar thermal standards into other standards is of increasing importance. For example, standards originating from the implementation of the Energy Performance of Buildings Directive (Directive 2002/91/EC) will support the use of solar thermal systems by characterising their benefits compared with other heating systems, provided their performance is calculated correctly. Since for these standards the performance of solar systems needs to be calculated in a simplified way, this is not self-evident and adapted calculation methods are required.

Increased consumer confidence in solar thermal products due to high product quality. This is mainly achieved through quality assurance measures based on the certification of products, installations and services, as well as the possibility to determine and assess the functionality and performance of the system in an easy and cost-effective way. For product certification, schemes will be available covering not only the solar thermal system itself but also the system delivering the auxiliary energy. The certification schemes will be implemented and accepted globally or at least Europe-wide.

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[10] For further information on Solar Keymark certification, see: www.solarkeymark.org.

Figure 36 - Dynamic solar simulator of the Research and Testing Centre for Solar Thermal Systems (TZS) at ITW, University of Stuttgart, Germany Source: ITW

3.7.3 MAIN CHALLENGES IN R&D AND OTHER ACTIVITIES

Theme 1: Implementing standards for new and innovative solar thermal components and systems

Standards represent a key element for a sustainable market development, provided they are of sufficient quality, are implemented and widely accepted. R&D and other measures are required to develop and implement standards for new products, for example: solar collectors' hydraulic connections, techniques to fix collectors on the roof and pipe connections to reduce installation costs and introduce fail-safe concepts. Elaboration of standards for collectors' sub-components like the absorber or storage components such as thermal insulation is important to facilitate the inter-changeability of these sub-components. Test methods and standards for the lifetime of solar components must be developed.

Theme 2: Integrating solar thermal in other generic standards

Since the standardization of the entire HVAC systems is progressing, including monitoring systems in 'smart buildings' and 'smart districts', the proper integration of solar thermal subsystems is crucial. R&D is needed to develop simplified methods to calculate the solar yield accurately e.g. for the standards required as a result of the Energy Performance of Buildings Directive (Directive 2002/91/EC) and other generic standards in the HVAC and building sector. This includes the development of easy to use models for planners, which are validated by measurements.

Theme 3: Implementing certification systems for high consumer confidence

The certification of products, systems and services is crucial to gain high consumer confidence. R&D and further activities are required to widen the scope of the successful Solar Keymark certification scheme to other system categories, such as combined solar thermal and heat pump systems. A single European-wide and eventually global certification scheme for products, systems and installers should be developed. The Energy Labelling for solar thermal systems, based on the Eco-design directive (Directive 2009/125/EC) with already established standards and certification schemes, should be harmonized. Harmonization is further needed for the CE-marking of collectors with regard to the various directives such as the Construction Product Directive (very large collector modules), the Pressure Directive (large collector modules) and the Low Voltage Directive (combined thermal and photovoltaic collector modules).

Theme 4: Implementing procedures for standardized commissioning and guaranteed performance concepts to achieve long-term operation with high efficiency

Standardized commissioning and solar yield evaluation methods are required to attract commercial investors, especially for investments in large-scale solar thermal systems. R&D is needed to identify and develop procedures and measuring equipment to evaluate the quality of installation and the functionality of the solar thermal system over a short period of time. Design, commissioning and monitoring procedures must be developed to enhance the confidence of investors, manufacturers, installers and project developers, and also to ensure the long term quality of solar thermal systems. This will reduce operating and maintenance costs, and guarantee a specific solar yield. These procedures must ensure the safety and robustness of the entire heating system, including the solar unit, and regulate defined routine checks. They will be supported by detailed system monitoring and failure self-detection functions. Due to the costs involved, the operating surveillance will be rather qualitative for smaller systems and more quantitative for medium to large solar thermal systems.

3.7.4 Priorities for R&D and activities

Priorities for R&D and activities for standards and quality assurance measures are:

up to 2020	beyond 2020
Development of : • test methods and European standards to characterize the performance and quality of new and innovative components and systems like concentrating and tracked collectors, PVT-collectors, thermo-chemical heat stores, solar thermal cooling systems, combined solar thermal and heat pump systems and systems for 'Solar Active Houses' • test methods and standards to characterize the quality and expected lifetime of all collector types • standardized connections between hydraulic, electric and mechanical components • certified easy to use simulation models of complex collectors for planners • simplified calculation methods for the proper integration of solar thermal into standards related to the Energy Performance of Buildings Directive (Directive 2002/91/EC) • concepts and procedures for standardized and solid monitoring of all types solar thermal systems at costs suited to the investment costs • standardized commissioning and solar yield evaluation methods for high efficient long-term operation Harmonization of : • energy labelling of solar thermal systems based on the Eco-design directive • CE-Marking of solar collectors Transformation of : • European standards for solar thermal products towards international (ISO) standards Elaboration and implementation of : • European product certification schemes • European installer certification schemes (volunteered or required) Establishment of a • globally uniform product certification scheme for solar collectors and systems based on ISO standards	Development of : • standards for components and systems available from 2020 onwards • standardised test methods for new storage materials e.g. thermo-chemical materials • advanced standardized commissioning and solar yield evaluation methods using technology available from 2020 onwards

3.8 NON-TECHNOLOGICAL PRIORITIES AND SUPPORTING MEASURES

Successful R&D in solar heating and cooling technologies does not solely depend on scientific and technological progress. Several non-technical barriers prevent successful innovations as well and must be removed in order to implement the strategic research agenda successfully.

3.8.1 STATE-OF-THE-ART

Since the huge technological development potential of solar heating and cooling technologies was not acknowledged in the past, it is only in recent years that universities have included this topic in their engineering courses. Therefore, the sector is lacking in experts and high and mid-level training. The scientific exchange on knowledge related to solar heating and cooling should be intensified. People from industry and the building sector must be trained to understand and be able to design and install solar heating and cooling systems and integrate them into HVAC and building systems. Moreover, several socio-economic aspects need to be addressed by specific research projects, including the lack of awareness of the solar heating and cooling potential, difficult access to finance, lack of adequate business models and low priority of energy issues compared with other costs.

3.8.2 DEVELOPMENT OBJECTIVES

A broad professional training and education system for installers up to high-level experts will be established to provide the capacities for implementing the SRA successfully. The complex and fragmented building infrastructure in European countries will be overcome by harmonized European education and training courses and structures.

A research infrastructure on solar heating and cooling technologies will be established in all European member states, combined with the implementation of a 'Joint European Solar Heating and Cooling Research Programme' to enable the implementation of the SRP. Since it is only recently that a few countries such as Austria, Germany and France started to systematically build up a research infrastructure in renewable heating and cooling technologies, there is still a huge demand for setting up a research infrastructure for the sector in Europe. The related activities should be supported by Horizon 2020 and the member states.

The acceptance of solar thermal systems in the residential and industrial sectors will be improved by information and dissemination activities and the development of new business and service models. Such socio-economic measures are needed to stimulate market development and investments in R&D for the industry. The lack of awareness of solar heating and cooling technologies; low priority of energy issues compared with other costs for individuals or companies; the absence of internalization of external costs in energy prices or purchasing costs, and efforts required for gathering information must be addressed. New approaches must be developed by socio-economic R&D to remove these obstacles. New business models will help to overcome the financial barriers for the deployment of solar heating and cooling technologies.

3.8.3 MAIN CHALLENGES IN R&D AND OTHER MEASURES

Theme 1: Introducing a broad professional training and education system

In Europe, courses on solar heating and cooling for professionals in the solar, energy and building sectors must be improved and harmonized. Some steps must be taken to develop both a harmonized curriculum for the education and training of professionals of all levels, and a European-wide training and education system. These will be targeting all professionals who are involved in or needed for the deployment of solar heating and cooling technologies in the building sector, e.g. installers, architects, engineering consultants, and contractors. Additional activities are required to meet the demand from the heating and cooling industry for skilled personnel. Not only academically-trained people but also vocational education will be vital to meet the technical challenges highlighted in this SRP. Certified training courses with a specific defined quality should be required to become a solar thermal installer.

Theme 2: Strengthening the solar heating and cooling research infrastructure

In Europe, the strategic development of a research infrastructure for solar heating and cooling is key for implementing the activities described in this SRP. Networking activities of European research institutes and industry in solar heating and cooling need some support and, for example, a 'Joint European Solar Heating and Cooling Research Programme' should be established, with some regional 'Solar Cooling Development Centres' and a 'European Institute for Thermal Energy Storage'. Besides the necessary investments in R&D infrastructure, virtual R&D cooperation should be stimulated by specific programmes. Cross-sectorial collaboration, e.g. the integration of SHC technology into the construction process and logistics chain, should be included. R&D should not only address the development of products for European, but also for the Mediterranean, Asian and other international markets e.g. on solar thermal cooling technologies. Test facilities for new applications like process heat and solar cooling components and systems should be set up at European level within a 'Joint Programme'. The launch of the 'European Institute for Thermal Energy Storage' should provide a broad research infrastructure, including testing equipment, which is necessary to meet the huge challenges of this strategically important technology. A wide exchange programme for master and PhD students within research institutes in all member states should create the basis for a European-wide network of scientists working in this field.

Figure 37 - Precision tracker to characterize façade, large-area and concentrating collectors. Source: Fraunhofer ISE

Theme 3: Developing socio-economic support activities

Since several socio-economic obstacles hinder the uptake of solar heating and cooling technologies, industry and research institutes are reluctant to increase their R&D investments. Activities are required, to improve the awareness and information dissemination of solar heating and cooling technologies. New business models must be developed to overcome the barrier for financing upfront costs. Concepts for outsourcing technical and economic risks, and offering further energy related services, should be developed as well. Innovative marketing strategies should be elaborated based on market research to stimulate the refurbishment of the existing building stock and heating systems with modern solar thermal heating systems. New business models for introducing solar process heat technologies should be developed, e.g. solar thermal energy service companies (ST-ESCOs).

3.8.4 PRIORITIES FOR R&D AND ACTIVITIES

Priorities for R&D and for non-technological activities and supporting measures are:

up to 2020	beyond 2020
Development of : • harmonized European training and education courses on solar heating and cooling technologies for architects, engineers, installers etc. • a European research network • a 'Joint European Solar Heating and Cooling Research Programme' to strategically develop European research on solar heating and cooling • a small number of 'Solar Cooling Development Centres' which are focussing on solar cooling technologies • a 'European Institute for Thermal Energy Storage' with a strong network to national storage scientists to bundle research capacities on this key enabling technology • new concepts for awareness dissemination measures in the heating and cooling sector based on research in social sciences • new business models for building owners, industries, ESCOs and investors	Development of : • new and innovative training and education concepts to educate professionals on new heating and cooling technologies

Appendix 1:

Terms and abreviations

CHP	Combined heat and power
CO2	Carbon dioxide
COP	Coefficient of performance
CPC	Compound parabolic concentrator
DH	District heating
DHW	Domestic hot water (heating)
ESCO	Energy services company
ESTTP	European Solar Thermal Technology Platform (2005 – 2008) European Solar Thermal Technology Panel (since October 2008)
EU	European Union
Gj	Gigajoule
HVAC	Heating, ventilation and air conditioning
ICT	Information and communications technology
kW, kWth, kWh	Kilowatt, kilowatt thermal, kilowatt hour
MW, MWth, MWh	Megawatt, Megawatt thermal, Megawatt hour
NREAP	National Renewable Energy Action Plans
O&M	Operation and maintenance
PCM	Phase change material
PVT	Photovoltaic-thermal hybrid collector
R&D	Research and development
RES	Renewable energy sources
RHC-Platform	European Technology Platform on Renewable Heating & Cooling
SDH	Solar district heating
SDHW	Solar domestic hot water
SRA	Strategic Research Agenda (elaborated by the RHC-platform and the former solar thermal platform ESTTP)
SRP	Strategic Research Priorities (elaborated by the technology panels of the RHC-platform)
ST	Solar thermal

Appendix 2:
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Appendix 3:
Solar heat costs

Solar heat costs in Europe

			DHW (Southern Europe) thermosiphon Southern Europe		**DHW (Central/Northern Europe)** forced circulation Central Northern Europe		**Combi systems** medium size Central/Northern Europe		**Industrial process heat** low to high temperature Southern/Central Europe		**District heating** with and without storage Central/Northern Europe	
Item	**Unit**	**Notes**	**low**	**high**	**low**	**high**	**low**	**high**	**low**	**high**	**low**	**high**
Typical system price (installed)	€/system	a)	750	3000	3500	7000	7500	14000	175000	400000	2000000	7000000
Collector area	m^2		2,4	2,4	5	5	10	12	500	500	10000	7500
Avoided costs	€/system	b)	150	150	800	800	800	800	0	0	0	0
Effective system price	€/m^2	c)	250	1188	540	1240	670	1100	350	800	200	933
Effective system price	€/KWth		357	1696	771	1771	957	1571	500	1143	286	1333
System O&M costs annually	%/a		1%	1%	2%	2%	2%	2%	2%	2%	2%	2%
System O&M costs during lifetime	€/m^2		38	238	216	496	268	440	140	320	80	373
Total costs - investment and O&M	€/m^2		288	1425	756	1736	938	1540	490	1120	280	1307
Total costs - investment and O&M	€/KWth		411	2036	1080	2480	1340	2200	700	1600	400	1867
Expected lifetime of the system	a		15	20	20	20	20	20	20	20	20	20
Discount rate	%		3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Capital recovery factor	%		8,38%	6,72%	6,72%	6,72%	6,72%	6,72%	6,72%	6,72%	6,72%	6,72%
Annual horizontal radiation	kWh/m^2	d)	1585	1585	1091	1091	1091	1091	1585	1091	1091	1091
Solar yield factor for type of system		e)	0,44	0,44	0,44	0,44	0,33	0,33	0,44	0,44	0,33	0,33
Annual solar energy yield	kWh/m^2		697	697	480	480	360	360	697	480	360	360
Cost of solar heat supplied	€-cent/kWh	e)	3	11	8	19	14	23	4	12	4	19

Notes:

a) Typical low/high system price (ready installed, inclusive VAT), source: ESTIF/ESTTP
b) Assumed cost of a conventional DHW system or components rendered obsolete or duplicate (incl. Labour and VAT)
c) Assumed overall system cost minus avoided costs (b)
d) Reference values for solar radiation on a horizontal plane for reference locations: Central Europe/ North Europe - Würzburg (DE) / South Europe: Athens (GR)
e) Typical conversion factor from horizontal radiation to collector output, depending on the type of system
f) Based on the common calculation method for solar collector energy output (IEA Solar Heating and Cooling Programme): http://www.iea-shc.org/common-calculation-method

Reference Systems:

DHW small - thermosiphon - Southern Europe : Thermosiphon for domestic hot water (DHW) preparation, with 2,4 m² flat-plate collectors, 150-180 lts store for 3-4 person household.

DHW collective - forced circulation - Southern Europe : Forced circulation system for DHW preparation using 50 m² flat-plate collectors with a 3 m³ buffer store for muitifamily house.

DHW (small & collective) - forced circulation - Central/Northern Europe : Small system: DHW forced circulation system with 3-4 m² flat-plate collectors and a 200-250 lts store for a 3-4 person household.

Collective system: DHW forced circulation system using 50 m² flat-plate collectors with a 3 m³ buffer store for muitifamily house.

Combi systems - medium size - Central/Northern Europe : Forced circulation system used for DHW and space heating with 12 m² flat-plate collectors and a 800 lts store for a 3-4 person household.

Industrial process heat - Southern / Central Europe : Large instalation used to provide industrial process heat, with 500 m² flat-plate collectors and 50 m³ buffer store.

District heating - Central/Northern Europe : Large solar district heating plant. High costs option includes seasonal heat storage costs. Low cost option does not incude such storage.

Appendix 4:

Secretariat of the RHC-Platform

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RHC Renewable Heating & Cooling

European Technology Platform

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