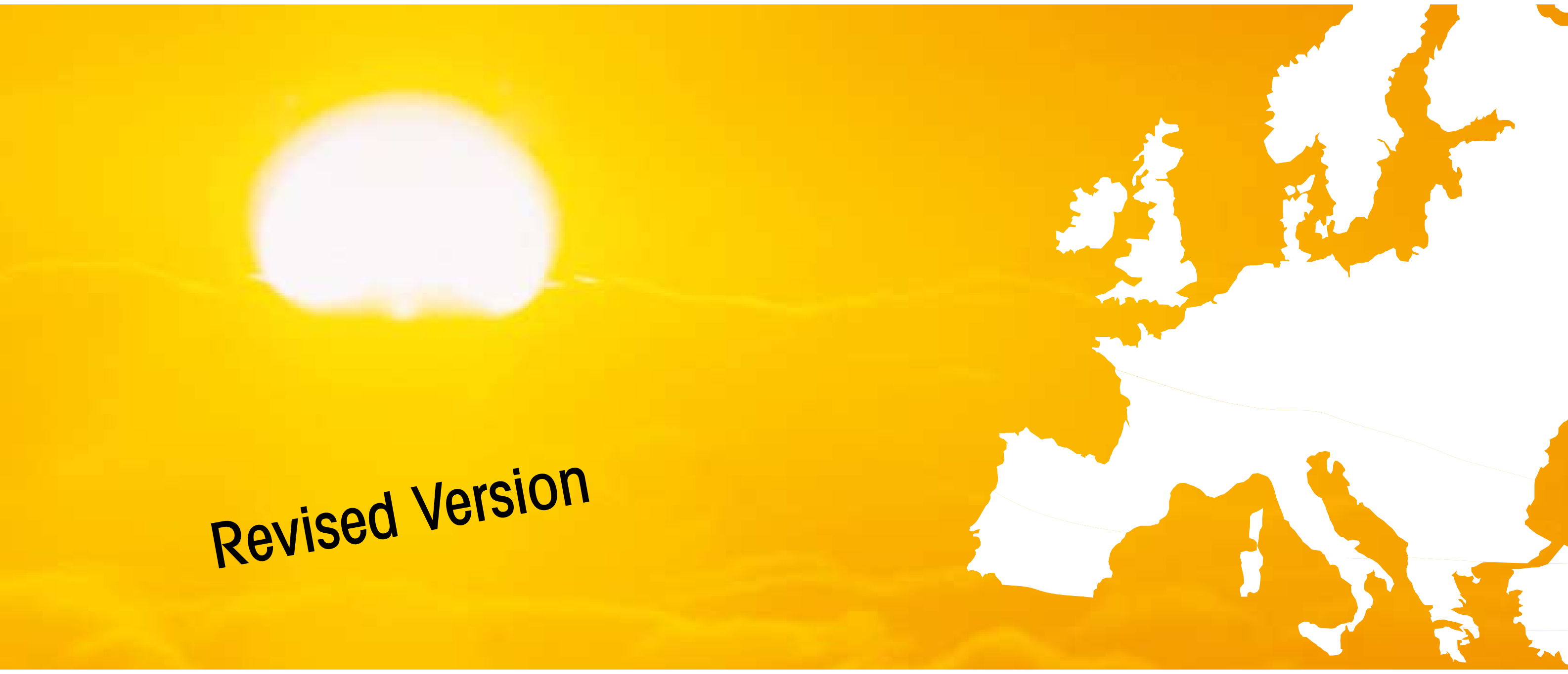
E S T T P

European Solar Thermal Technology Platform



Solar Heating and Cooling for a Sustainable Energy Future in Europe

Vision
Potential
Deployment Roadmap
Strategic Research Agenda

SIXTH FRAMEWORK PROGRAMME

Image on Title: The Sun

(Source: Triolog, Freiburg, Germany)

Solar Heating and Cooling
for a Sustainable Energy Future in Europe

Imprint

This document was prepared by the European Solar Thermal Technology Platform (ESTTP).

SIXTH FRAMEWORK PROGRAMME

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1 Foreword

Dear Reader,

For a long time, low-temperature solar thermal has only played a minor role compared to other renewable energy sources. The popular conception concerning energy was focused almost exclusively upon electricity generation, even though heating constitutes almost 50% of the total energy consumption. Solar thermal was considered mainly to provide for water heating needs, where technologically mature solutions exist. In the scenarios of future energy strategies, heat generation consequently played only a very small role.

The situation has changed dramatically. Without a doubt, the European goal of covering 20% of energy needs with renewable energy can only be reached with a significant increase of renewable energy capacities in the heating sector. The explosion of crude oil and natural gas prices along with increasing import dependency have further increased public attention and interest. However, the question remained which role solar heating was supposed to play.

At the same time, it is nothing new that low-temperature solar thermal technology has the greatest potential among all renewable energies in the heating area. Today, it are primarily the advancements made by the European Solar Technology Platform (ESTTP) that outline the large technological development potential of low-temperature solar thermal. This potential is triggered by the enhancements to system types and components but also primarily in the development of new uses for the technology, such as solar heating, process-heating generation, district heating and solar assisted cooling.

Already in 2006, the ESTTP formulated its 2030 vision for low-temperature solar thermal. Since then, numerous experts from the industry and research sectors of Europe have worked on a strategic research agenda to implement this vision. With this document, you hold the results of this work in your hands. It is the first time that the technological perspectives of low-temperature solar thermal have been so systematically presented. It will certainly contribute to evaluate the opportunities for solar thermal more realistically.

Out of this research program comes the challenge of overcoming the research funding deficits of the previous years. Low-temperature solar thermal must play an important role in the research programs of the EU and the member states. The funding for solar thermal research must be significantly increased and the research capacities must be systematically expanded.

I would like to thank all of the experts who have been involved in this extensive task and cordially invite all who are interested to use this document to obtain a comprehensive overview of the technological perspectives on low-temperature solar thermal and work together with us to implement this research strategy. On this note, I wish you a most interesting read.

Sunny regards,

Gerhard Stryi-Hipp

The paper has been written by the European Solar Thermal Technology Platform (ESTTP). The ESTTP was co-founded and is supported by the European Solar Thermal Industry Federation (ESTIF) and the by EUREC Agency, an association representing the European research institutes active in the renewable energy field.

2 Executive summary

Solar thermal energy is an extremely convenient source of heating; and a technology that does not rely on scarce, finite energy resources. It has the potential to cover 50% of the total heat demand. To reach this goal existing technologies have to expand and new technologies should be developed for new sectors like apartment buildings and the industrial sector. Research is needed for new applications like, compact seasonal storage, industrial applications (up to 250 °C) and solar cooling.

In this document the current trends and technological perspective is described and the vision for 2030. Then the deployment road map is given to reach this perspective. The strategic research agenda and the research infrastructure needed for reaching the goals are described in the chapter 8 and 9.

This vision, deployment road map and research agenda was developed by the European Solar Thermal Technology Platform (ESTTP). The ESTTP was set-up by the European Solar Thermal Industry Federation (ESTIF) and the European Renewable Energy Research Centres Agency (EUREC Agency). In the platform about 100 leading experts in the field of solar thermal research and applications co-operated to write this report.

The main findings of this report are:

Current status

- The demand for heating and cooling is 49% of the total energy demand in Europe, most of which is needed at low- to medium temperatures (up to 250°C).
- Technologies are available or can be developed to cover in principle most of this demand.
- Solar thermal applications do not depend on finite sources and solar energy is available everywhere.
- Already today, solar thermal energy for domestic hot water preparation and for space heating is a developed technology with a high penetration rates in some countries.

Vision 2030

- Solar thermal can cover 50% of the total heat demand, if the heat demand is first reduced by energy saving measures.
- To reach this goal new applications have to be developed and deployed. The main ones are the active solar building, the active solar renovation, industrial applications up to 250 °C, solar heat for district heating and cooling.

Figure 1 shows how this long term goal of the vision can be reached and how this is split over current technologies (business as usual), advanced market deployment (by developing new technologies and application sectors) and new applications where R&D is needed to develop them (like compact heat storage and high temperature collectors)

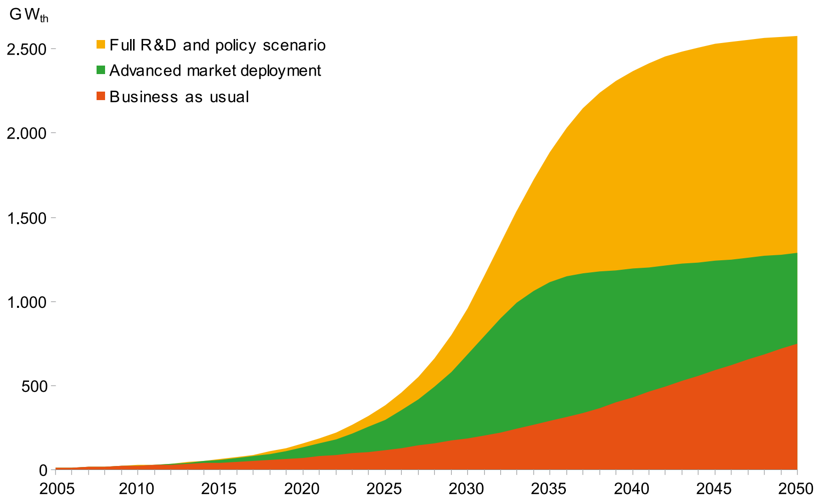


Figure 1: Growth in solar thermal energy use in different scenarios. (Source: ESTIF, 2008)

Figure 2 shows how this target of 50% compares to the total heat demand. First the energy demand can be reduced by 40% and from this reduced demand solar can contribute 50% in the long run (around 2050). The division over the application sector is included.

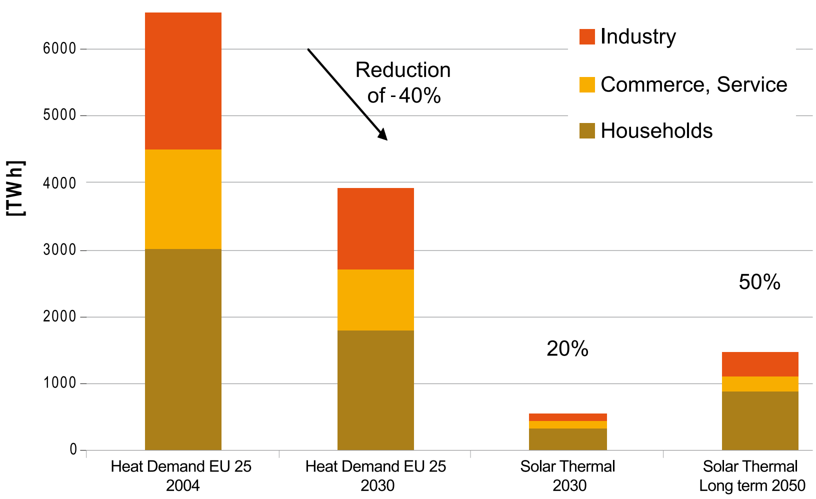


Figure 2: Contribution of solar thermal to EU heat demand by sector, assuming that the total heat demand can be reduced by energy conservation and a 40% increase in efficiency by 2030. (Source: AEE INTEC, 2008)

Deployment roadmap

The deployment roadmap shows what research, development and demonstrations are needed to develop the main application fields: residential & commercial buildings, industrial process heat, desalination and water treatment and district heating. Beside the technological developments also the market issues are described.

The strategic research agenda

To reach the goal of supplying 50% of the heat demand, a new generation of solar thermal technologies need to be developed for new application areas. The main new applications are: solar combi-systems using compact seasonal storage, higher temperature collectors for industrial applications and solar cooling. The main research challenges are:

- To develop compact long-term efficient heat storage. The storage technology should make it possible to store heat from the summer for use in winter in a cost-effective manner
- To develop new materials for solar systems. The new materials are needed because the materials as currently applied have a limited technical performance and could potentially be replaced with cheaper options.
- Basic research for improvement in solar cooling, high temperature solar collectors and solar desalination.

For each application field the industrial development and the basic research that is needed is described in detail.

The research infrastructure

The Research Infrastructure needed to implement the Research Agenda is a structured collaboration of research institutes and industry.

It includes:

- a RD&D Network;
- a Joint European Laboratory dedicated to solar cooling and process heat; and
- Regional Solar Cooling and Process Heat Development Centres for demonstration, technology transfer and training.

Future actions

To reach the goals, a whole range of activities is needed from basic research to promotion, because solar thermal is a technology that includes applications that are cost-effective (like solar water heaters in sunny climates) to completely new technologies (like compact chemical heat storage). The development of the current markets is the basis. With these existing technologies new application areas, like industrial heat and multi-family houses can be developed. Improved technologies can further open these markets and expand them to solar cooling, solar desalination and higher temperature applications. Basic research should lead to a new generation of solar technologies like seasonal storage of solar heat and a new generation of solar systems with improved price performance.

The Earth seen from Apollo 17

Source: http://de.wikipedia.org/wiki/Bild:The_Earth_seen_from_Apollo_17.jpg
(Author: Image courtesy of Earth Sciences and Image Analysis Laboratory,
NASA Johnson Space Center. File Name AS17-148-22727;
created by NASA)

3 About the European Solar Thermal Technology Platform

3 About the European Solar Thermal Technology Platform

This document has been produced by the European Solar Thermal technology Platform (ESTTP).

Technology Platforms are seen as a very important tool to frame and promote the future development of a technology. In order to strengthen the pan-European understanding and development of solar thermal technology an Initiator Group has been working towards a ESTTP since the beginning of 2005.

Several active members of the European Solar Thermal Industry Federation (ESTIF) and the European Renewable Energy Centres Agency (EUREC Agency) founded the ESTTP Initiator Group. Both organisations strongly support the platform. Furthermore it involves "neighbouring" industries (for example, from construction, heating ventilation and air conditioning and metals sectors) as well as policy makers.

The diagram below shows the structure of the Technology Platform.

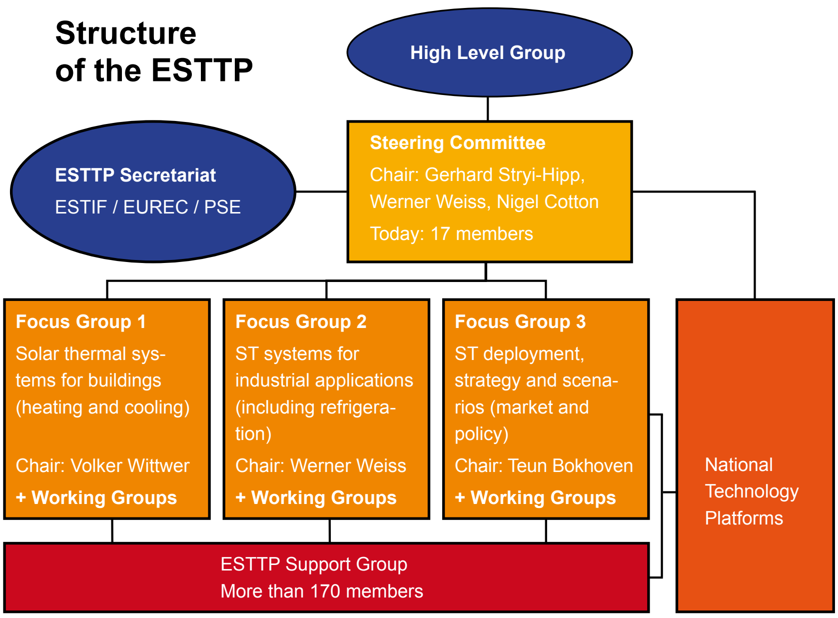


Figure 3: Current structure of the European Solar Thermal Technology Platform

High level Group: Consists of CEOs and representatives from the European Commission and national ministries. It provides direction and advice on the work of the Technology Platform.

Steering Committee: Is responsible for managing the Technology Platform.

Focus Groups: Coordinate the activities of one field of research and provide information for a wide number of members interested in a particular field of solar thermal research such as the building sector, industrial applications or market and policy issues. The Focus Groups are subdivided into 12 working groups.

Working Groups: Work on different issues, such as fundamental research, applied research, market deployment and political instruments. These groups take responsibility for progressing the work at a detailed level. All interested European experts can apply for membership.

National Mirror Groups: Work on a national level to provide input for the ESTTP and harmonise the European and national research agendas. National mirror groups will be initiated by national experts.

Support Group: More than 180 companies, R&D institutes and associations have become Support Group members. The Support Group comprises all companies and organisations that have signed the letter of support for the ESTTP. They are invited to participate in the ESTTP working groups and to attend General Assemblies.

Structure of Focus and Working Groups

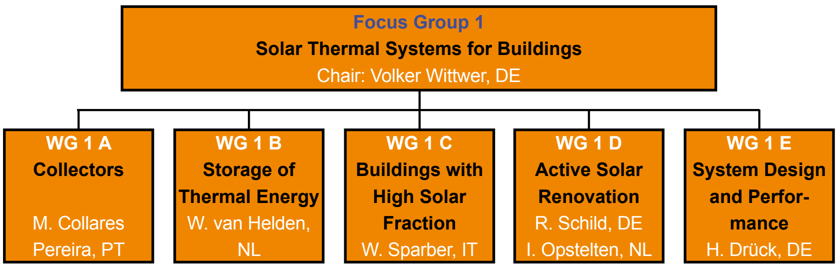


Figure 4: Structure of Focus and Working Groups 1

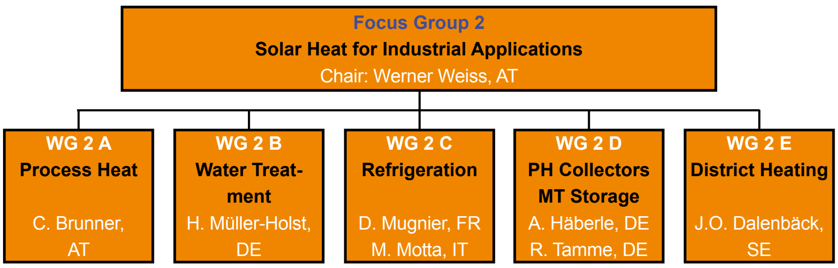


Figure 5: Structure of Focus and Working Groups 2

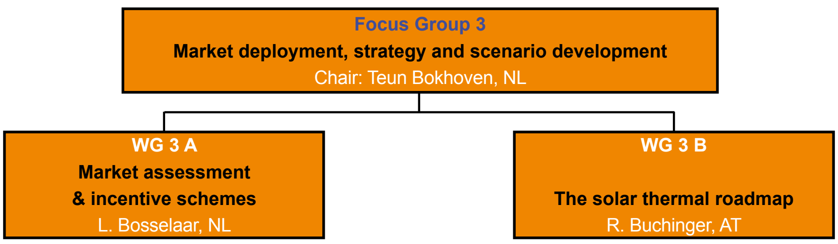


Figure 6: Structure of Focus and Working Groups 3

Diameter comparison of Sun and Earth

Source: http://de.wikipedia.org/wiki/Bild:Sun_Earth_Comparison.png
(created by NASA)

4 The unique benefits of Solar Thermal

4 The unique benefits of Solar Thermal

Heating accounts for a significant proportion of the world's total energy demand. The building sector alone consumes 35.3%, of which 75% is for space heating and domestic water heating (IEA, 2006). Besides buildings, there is substantial heat consumption for industrial processes and heat-intensive services.

In Europe, the final energy demand for heating and cooling (49%) is higher than for electricity (20%) or transport (31%) (EREC, 2006).

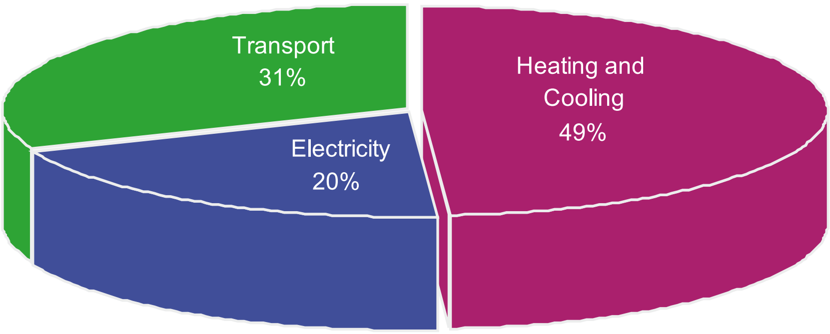


Figure 7: Final Energy demand in the European Union. (Source: EREC, 2006)

In the past, the heating sector has been traditionally neglected in the energy policy debate. Now it is becoming increasingly evident that the renewable heating and cooling (RES-H/C) sector must play a major role in reaching the European policy goals in terms of reducing greenhouse gas emissions, increasing the renewables share in the energy mix, and reduction of the dependency on imported fossil fuels.

Of course, RES-H/C deployment must go hand in hand with a substantial improvement in the energy efficiency of buildings and of heat consuming processes. It is imperative that both pathways develop as rapidly as possible to dramatically increase efficiency and to replace the remaining heating and cooling demand by RES. Higher efficiency values create the neccessary conditions for a fully renewable supply of thermal energy demand, freeing the scarce fossil fuel resources for other purposes where they are less easily replaceable.

During the coming years and decades, fossil fuels and nuclear power will become increasingly scarce and expensive as a result of the exhaustion of natural resources and the climate change mitigation policies. This process has obviously already started. Therefore, using fossil fuels or electricity as the main resource to achieve the low temperatures required for heating and cooling buildings will become too expensive for most people and will be seen as an unacceptable squandering of resources.

Certainly, the use of biomass and heat pumps will rise significantly. However, scarce biomass resources are needed to fulfill the demand from other energy and non-energy fields, while a wide deployment of heat pumps as a main source of heating would imply a massive increase in electricity consumption, with strong economic and environmental external costs. Therefore, solar thermal (ST) will become an indispensable and crucial pillar of the future energy mix for heating and cooling.

Within the RES-H/C portfolio, ST has unique and specific benefits:

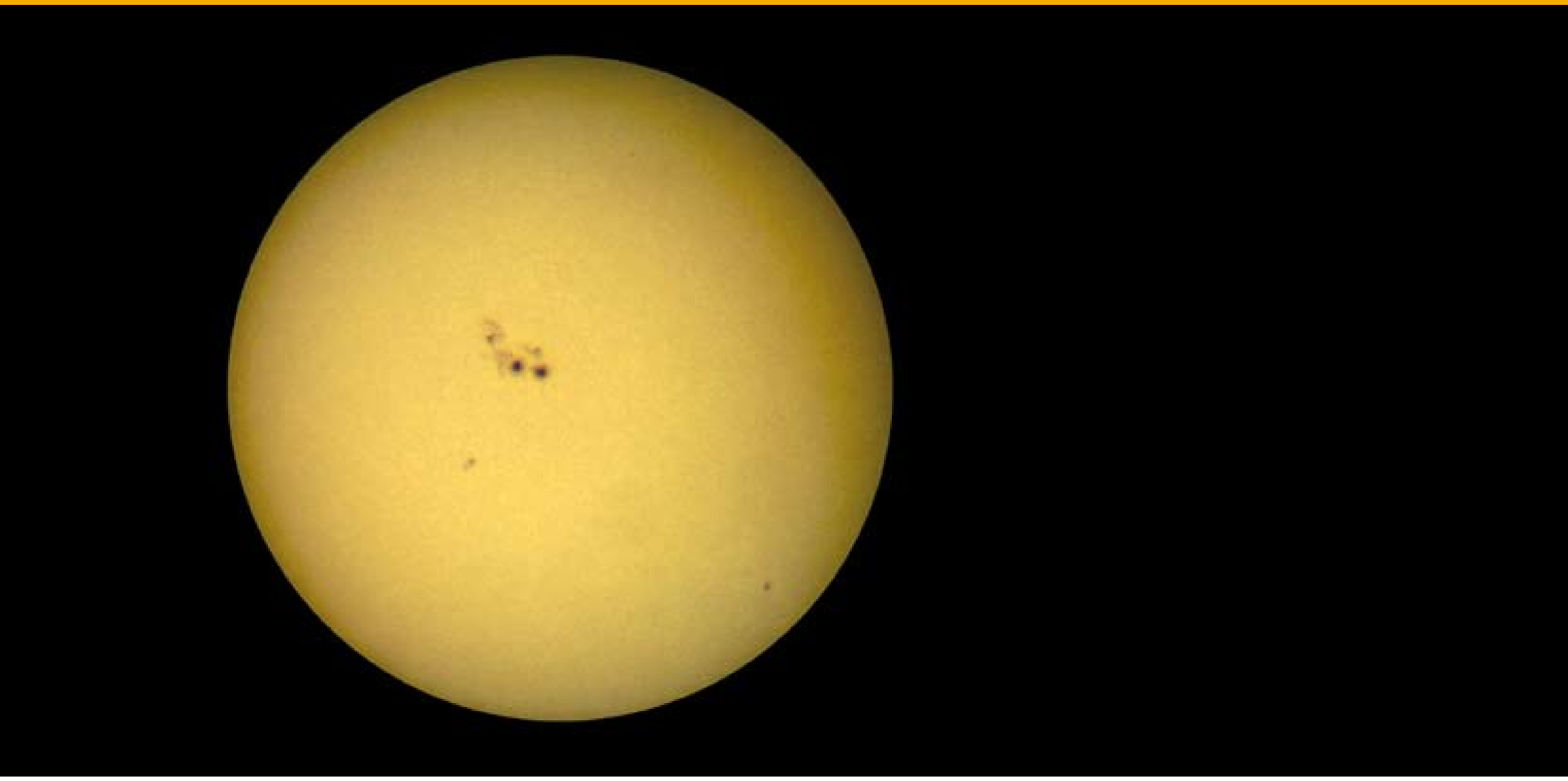
- ST always leads to a direct reduction of primary energy consumption
- ST can be combined with nearly all kinds of back-up heat sources
- ST has the highest potential under the RES-H/C-technologies and does not rely on finite resources, needed also for other energy and non-energy purposes
- ST does not lead to a significant increase in electricity demand, which could imply substantial investments to increase power generation and transmission capacities
- ST is available nearly everywhere. Current limitations, for instance at very high latitudes or in case of limited space for heat storage, can be largely overcome through R&D, as shown later in the present document
- ST prices are highly predictable, since the largest part of them occur at the moment of investment, and therefore does not depend on future oil, gas, biomass, or electricity prices
- The life-cycle environmental impact of ST systems is extremely low
- ST replaces (mainly imported) natural sources with local jobs. Wherever the ST hardware will be produced in the future, a large portion of the value chain (distribution, planning, installation, maintenance) is inherently related to the demand side

Solar thermal is therefore the absolute best option for fulfilling the long-term heating and cooling supply. In the long-term, the goal will be to meet our heating demand as much as is technically possible with solar energy; preserving the scarce electricity, biomass and fossil fuel resources for instances where solar heating is not yet available at acceptable costs.

In principle, most people would agree with these statements. However, in the past many did not regard solar thermal as an important pillar of the energy supply system since they could not imagine the huge technological potential of solar thermal. These advantages will be described in the following chapters.

Ocular projection of the sun with large sunspots using a spotting scope

Source: http://de.wikipedia.org/wiki/Bild:Sun_projection_with_spotting-scope_large.jpg
(GNU Free Documentation license; Photographer: SiriusB)



5 A technological perspective on Solar Thermal potential

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The independent Global Climate Decision Makers Survey (GCDMS, 2007) presented in December, 2007 at the UN Climate Change conference in Bali showed that, among approximately 20 carbon reduction technology options, solar thermal and passive solar are considered over the next 25 years to be technologies with the highest carbon reduction potential without unacceptable side effects. This shows that politicians and experts are becoming increasingly more aware of the importance of harnessing the potential of ST.

Despite these realized benefits, widespread usage is still a long way away and we must intensify our efforts in order to make the ST potential fully feasible. Today, ST is mainly used in the heating of domestic hot water. The share of systems which are supporting space heating is presently small, yet growing. Up until now, ST systems are almost exclusively used in residential homes. Thereby we must follow four strategies simultaneously to develop the full potential of ST.

1. The number of solar thermal systems has to be sharply increased (market deployment measures are needed)
2. The share of solar thermal energy which is covered by a ST system per building has to be increased step-by-step up to 100% (market deployment and R&D measures are needed)
3. ST has to be introduced in new market segments like the commercial and industrial sector (R&D and market deployment measures are needed)
4. New ST applications, e.g. Solar Assisted Cooling and process heating have to be developed (strong R&D and market deployment measures are needed)

5.1 Current trends in the ST market

ST is becoming more and more popular in a growing number of countries worldwide. The worldwide market for ST systems has been growing continuously since the beginning of the 1990s. In Europe, the market size nearly tripled between 2002 and 2006. Even in the leading European ST markets Austria, Greece and Germany, only a minor part of the residential homes are using ST. In Germany, about 5% of one and two familiy homes are using ST energy.

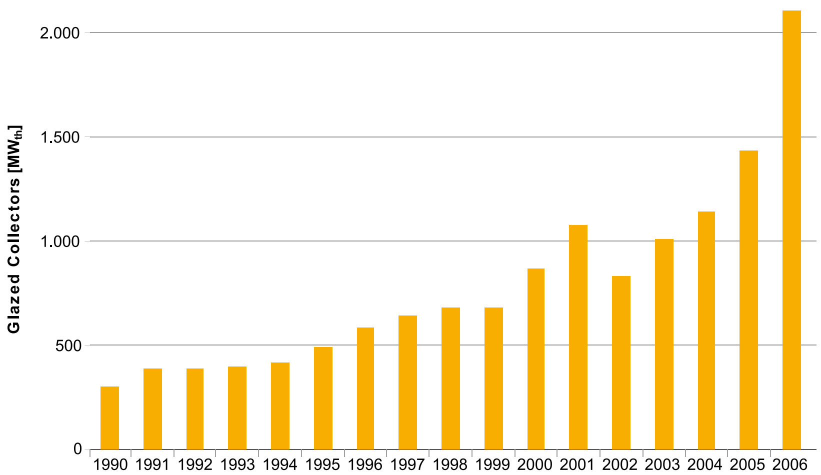

Figure 8: Market development of solar thermal in the European Union. (Source: ESTIF, 2007)

Other European countries are now systematically developing their ST markets as well, such as Spain, France, Italy and the UK. However, both within Europe and at a global level, the ST market development has been previously characterized by huge gaps between a small number of frontrunner countries and a large number of countries which are still in the starting blocks.

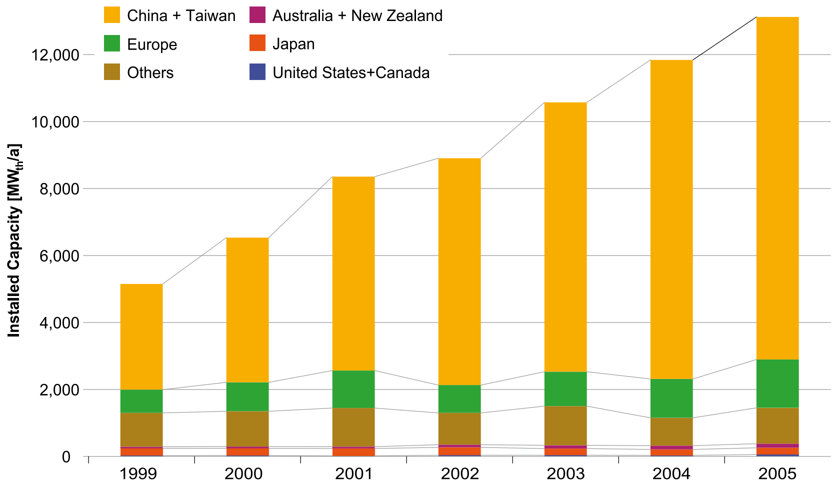

Figure 9: Annual newly installed capacity of flat-plate and evacuated tube collectors in kW_{th} by economic region. (Source: IEA, 2007)

The chart above shows that, in absolute terms, China by far comprises most of the ST market worldwide. In spite of the strong technological leadership of the European ST industry and the high variety of available ST technology, Europe has only a small market share worldwide, whereas North America and Oceania still play an insignificant role. Among the "others", ST is mainly used in Turkey, Israel and Brazil.

The chart below reviews the same data, but per capita.

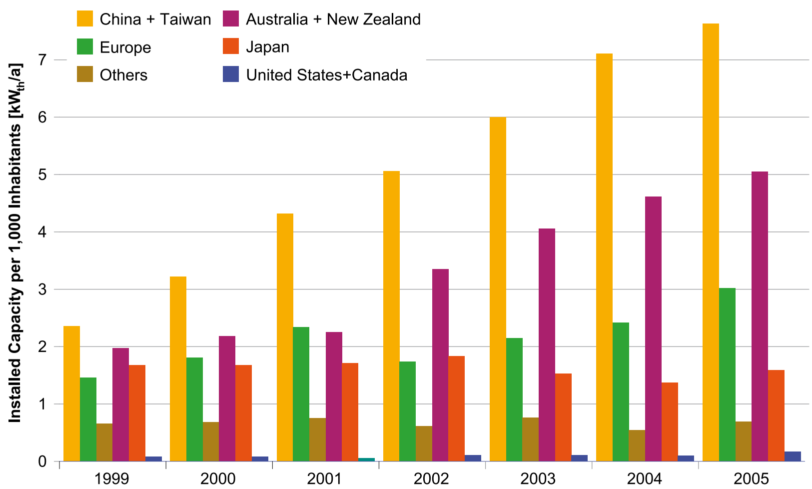

Figure 10: Annual newly installed capacity of flat-plate and evacuated tube collectors in kW_{th} per capita. (Source: IEA, 2007)

Taking into account the population, the Chinese leadership is less strong, while Oceania, Europe and Japan are in a better position. However, the huge imbalance between different regions remains impressive.

Even stronger gaps are registered within Europe.

Solar Thermal Markets 2006 in Europe

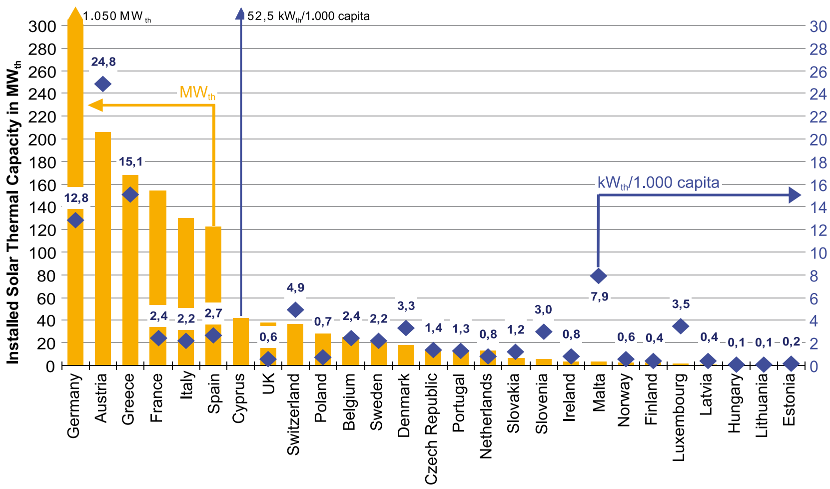

Figure 11: ST capacity installed in 2006 in different European countries total (orange bars) and per capita (blue dots). (Source: ESTIF, 2007)

Figure 11 shows that Germany has by far the biggest ST market, followed by Austria, Greece, France, Italy and Spain. All of the other European countries have relatively small market as of now. However, this order is different if one looks at the ST market per capita. While Cyprus enjoys particularly favourable conditions, Austria is a rather average country, considering its climate, building stock and prevailing heating systems. However, with over 250 kW$_{th}$ by Mid 2008 per 1000 inhabitants, Austria is more than six times ahead of the EU average, and 10-40 times ahead of most other countries, including those with high potential such as Italy, Spain and France.

It is evident that these huge gaps between neighbouring countries are not due to such dramatically different technological barriers or objective conditions, but mainly to market dynamics and political framework conditions.

Even in Austria, with its comparatively large stock of ST capacity, there is not the slightest sign of market saturation. If the current trend in the Austrian ST market continues, Austria will reach the per capita level of Cyprus in less than a decade.

5.2 Short-medium term ST potential

ST will cover 50% of the heating demand in Europe in the long term when ST will be used in almost every building, covering more than 50% of the heating and cooling demand in refurbished buildings and 100% in new buildings. ST will also be used in district heating systems, and in commercial and industrial applications with many new and improved ST technologies. But what could be the short-medium term ST potential?

With the current ST technologies, the **European short-medium term ST potential** is certainly substantially higher than the level of Austria (ca. 250 kW_{th} per 1.000 capita). Also, it is higher than the level of Cyprus today, where solar thermal is currently used almost exclusively for domestic hot water (DHW) preparation. Moving the entire EU to the current level of Cyprus would imply multiplying the ST capacity in operation by 15 in the EU. This shows that, for the next two decades, the available technology is definitely not a factor limiting growth! Technological development will also certainly help speed-up the market penetration of solar thermal in the short-medium term. However, the main barriers to growth are still of a non-technological nature.

ESTIF sets the goal of one m^2 solar capacity in operation until 2020 as a short-medium goal, which is equivalent to a capacity of 700 kW_{th} per 1000 capita. ESTIF's Solar Thermal Action Plan for Europe (www.estif.org/stap) offers a systematic analysis of the barriers to growth of solar thermal with existing technologies, and guidelines how to overcome them through industry actions and public policies. It can be expected that the upcoming EU Directive will reduce these gaps and allow for a more rapid exploitation of the short-medium term ST potential. The increased market volumes will provide the ST industry the means for a substantial increase in R&D investments. This will extend the boundaries of the ST potential, opening the way for the implementation of the ESTTP's vision for 2030.

5.3 Main applications in short-medium term

Compared to other continents, Europe has the most sophisticated market for different solar thermal applications, with a relatively wide mix of different applications such as hot water preparation, space heating of single- and multi-family homes and hotels, large-scale plants for district heating as well as a several pilot systems for air conditioning, cooling and industrial applications.

However, also in Europe, the majority of the new ST systems are installed on residential homes for heating domestic hot water (DHW) only, with typical solar fractions (i.e. the share of DHW demand covered by solar) in the range of 40-80%. Nevertheless, there is already a clear tendency towards combined ST systems for DHW and space heating support in countries like Germany and Austria, where 50% or more of the newly installed systems are combined systems.

Additionally, in markets like Spain, France and Austria, large ST collective systems for multi-family homes have a significant share. The systematic development of the market for collective ST systems is important to reach the short-medium term goals, since the majority of the European population is living in such homes.

5.4 Medium-long term ST potential (advanced technologies)

By overcoming a series of technological barriers, which are analyzed in detail below, it will be possible to achieve a wide market introduction at competitive costs of advanced ST applications like:

- Solar Active Building, covering at least 100% of their thermal energy with solar, and in some cases providing heat to neighbours
- High solar fraction space heating for building renovations
- Wide use of solar for space cooling
- Wide use of solar for heat intensive services and industrial process heat, including desalination and water treatment

These are the key elements of the ESTTP Vision, Deployment Roadmap and Strategic Research Agenda discussed below.

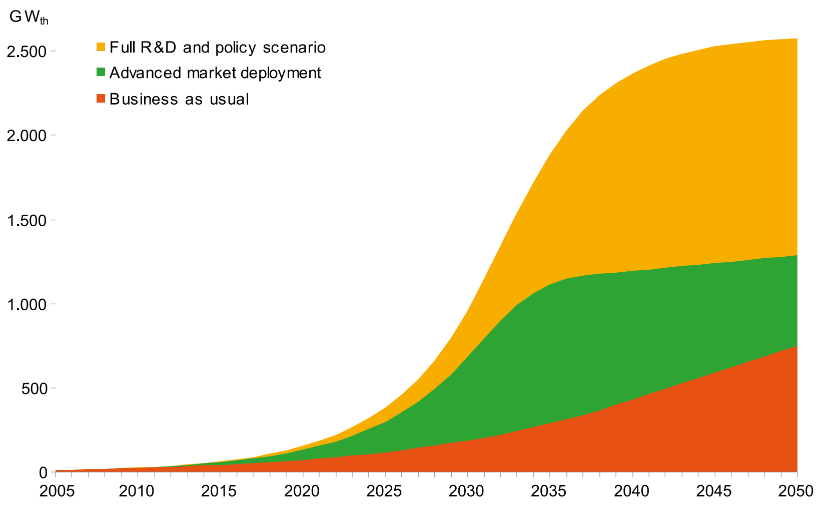

Figure 12: Growth in solar thermal energy use in different scenarios. (Source: ESTIF, 2008)

By implementing them, the potential for economically viable ST usage can be substantially expanded. This expansion is reflected in the following, simplified diagram. The lower curve (orange area) is a "business as usual" scenario based on a moderate growth rate. The middle curve (green area) is a scenario based on an advanced market deployment of current ST technologies through strong support policies. This leads to relatively high growth rates in the first period, but after a certain period of time the achievable potential with current technologies begins to become saturated and therefore the growth in capacity starts to stagnate at a relatively low level.

The higher curve (gold area) assumes both an advanced deployment of current technologies and strong private and public R&D investments. The technological progress leads to a full exploitation of the ST potential, thus using solar energy to fulfill a substantially higher share of the total demand for heat and cold. Saturation is reached later, and at a higher level of capacity.

Based on political support mechanisms, technical developments based on increased R&D and on independent report[1] calculations of the ESTTP show realistic growths rates of 20% in the solar thermal market.

These growth rates would lead to an installed capacity of 970 GW_{th} by 2030 in the EU. Based on the EU-25 heat demand of the year 2004 (AEBIOM, 2007), these solar thermal collectors could supply about 8% of the total heating demand. Combined energy conservation measures and increased efficiency in the building sector (-40% heat demand compared to 2004) would enable solar thermal systems to supply about 20% of the overall heat demand in EU-27 by 2030.

The long-term potential (2050) of solar thermal is to provide for about 50% of the EU´s heat demand. In order to achieve this goal an installed capacity of 2576 GW_{th} or 8 m^2 per inhabitant would be necessary.

1 Sustainability Report of the Swiss Sarasin Bank

Sun photo with hydrogen alpha filter

Source: http://de.wikipedia.org/wiki/Bild:Son-1.jpg
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6 Vision 2030

6 Vision 2030

The ESTTP's main objective is to create the right conditions in order to fully exploit solar thermal's potential for heating and cooling in Europe and worldwide. This would ensure long-term technological leadership of the European industry.

The achievement of this potential will not be completed by 2030. However, under positive framework conditions, it will be possible to substantially expand the use of solar thermal, and to set the technological basis for achieving full potential in the following two decades.

As a first step for the development of the Deployment Roadmap and of the Strategic Research Agenda, the ESTTP has developed a vision for solar thermal in 2030. Its key elements are to:

- establish the **Active Solar Building** as a standard for new buildings by 2030 - Active Solar buildings cover 100% of their heating and cooling demand with solar energy;
- establish the **Active Solar Renovation** as a standard for the refurbishment of existing buildings by 2030 - Active Solar renovated buildings are heated and cooled by at least 50% with solar thermal energy;
- satisfy with solar thermal energy a substantial share of the **industrial process heat demand up to 250°C**, including heating and cooling, as well as desalination and water treatment and a wide range of other high-potential processes; and
- achieve a broad use of solar energy in existing and future **district heating and cooling networks**, where it is particularly cost effective.

The following sections discuss certain economic implications of this vision. Subsequent chapters consider the Deployment Roadmap for the different applications, and the Strategic Research Agenda required to achieve this vision.

6.1 Macro-economic benefits

Solar thermal energy replaces imported fuels with local jobs. There would also be many other economic benefits resulting from the full exploitation of the ST potential. By implementing the ESTTP Vision, the EU would save approximately 47 Mtoe per year by 2030, and 126 Mtoe per year by 2050. The economic value of this would be significant, but cannot be quantified without knowing the prices and quantities of oil, gas, electricity and biomass for heating in the years discussed.

Beyond a reduction in energy bills, the advantage of highly predicable prices for heating and cooling must also be considered. The majority of ST costs are incurred at the initial investment stage, so can be easily predicted. Conversely, the total costs of all other heating supply technologies depend largely on the unpredictable future development of fuel and/or electricity prices. If ST were to be fully exploited, it would significantly reduce the macro-economic risks linked to the fluctuation of energy prices and the security of energy supply.

A high share of solar energy in the heat supply will also have benefits in terms of social policy. The high oil prices have become a substantial threat to low-income households in Europe. Several Member States recently increased financial support to those households that cannot afford the current heating oil and gas prices ("heating aid", for example the French Government's announcement on 11 November 2007 to double heating aid from €75 to €150 per household, thus earmarking a total of 70 million Euro to offset the negative economic effect of high fossil fuel prices).

Currently, at least 80% of the solar thermal value chain serving the EU market is based in the European Union, including:

- over 90% of manufacturing;
- almost 100% of sales and marketing; and
- 100% of installation and maintenance (which are inherently local and always create local jobs and wealth).

Only raw materials are largely imported (see below for more details on employment).

By helping to increase the uptake of solar thermal, the ESTTP improves Europe's trade balance and lowers the running costs of both businesses and private households.

6.2 Cost competitiveness

Improved competitiveness is necessary for moving from early markets to mass markets. Under positive boundary conditions, solar domestic hot water is often already cost-competitive with fossil-fuel based technologies, if considered over the lifetime of the solar system. Applications for space heating in multi-family houses, as well as solar assisted district heating are also close to competitiveness. These applications have the potential for short payback times. They are reliable, but their higher initial investment costs means they appear more expensive to potential purchasers when compared with conventional heating systems. However, this is not the case if costs are compared over a full life cycle.

Practical experience shows that cost competitiveness does not automatically lead to a mass market. There are plenty of potential energy efficiency measures with a return on investment of only two or three years, and still they remain unused. In economic terms, this may be due to incorrect information about the perceived transaction costs. In practical terms, it may be due to inertia, lack of information, lack of financial resources and other priorities, or the effects of publicity.

This means that cost competitiveness does not necessarily create a mass market for a product. However, it can be assumed that moving towards a mass market will be easier, as return on investment times become shorter.

The table below shows a range of prices for heat generated by a solar thermal system, compared to the current price of gas and electricity for the end user, and the price projected for 2030. Inflation is not taken into consideration.

Cost in €-cent per kwh				
	Today		2030	
	Central Europe	Southern Europe	Central Europe	Southern Europe
Solar thermal	7 - 16	5 - 12	3 – 6	2 - 4
Natural gas	8,5 - 29		17 - 58	
Electricity	7 - 33		14 - 66	

The costs of solar heat include all taxes, installation and maintenance. The spread is wide, because the total costs vary strongly, depending on factors such as:

- quality of products and installation;
- ease of installation;
- available solar radiation (latitude, number of sunny hours, orientation and tilting of the collectors);
- ambient temperature; and
- patterns of use determining the heat load.

By 2030, it is assumed that technological progress and economies of scale will lead to around a 60% reduction in costs.

The current costs of gas and electricity are based on Eurostat data, pertaining to private households for the second quarter of 2007 with a small load, and including all taxes. The cost of heating equipment is not taken into account, as this is deemed to be a necessary back-up for a solar thermal system. To reduce the effect of outliers, the cheapest and the most expensive countries have not been taken into consideration. The current price levels are somewhat underestimated. Eurostat has data from all 10 Eastern European new Member States and from Croatia. However, it only has figures from 4 of the EU-15 countries, where final user prices tend to be higher. It should also be stated that larger customers, such as big business, are able to obtain lower prices and do not pay VAT. The assumption underlining the 2030 prices is an average 3% annual real increase in the cost of electricity and associated prices, which is clearly lower than during the last decade. Inflation is not taken into consideration.

While important cost reductions in solar thermal can be achieved through R&D and economies of scale, the table shows why ESTTP's priority is to enable the large-scale use of solar thermal energy through the development to mass market of new applications, such as Active Solar Buildings, solar cooling, process heat, and desalination.

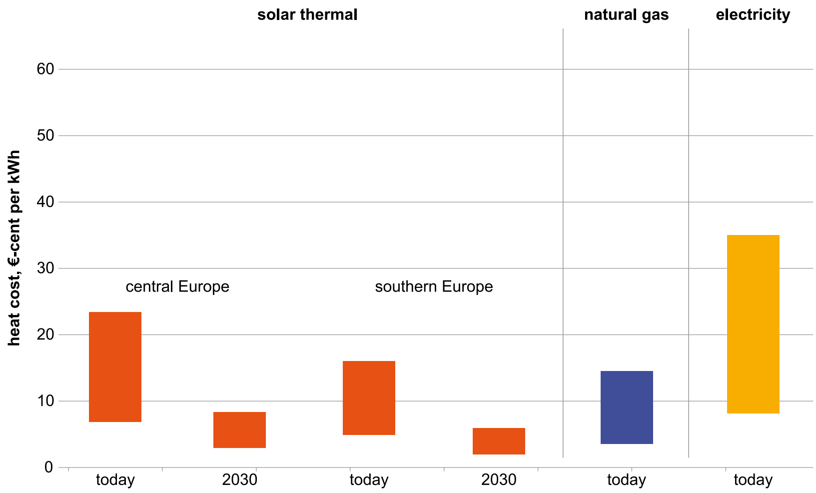


Figure 13: Typical cost ranges of domestic water/space heating with solar thermal, gas and electricity. (Source: ESTIF, 2008)

Over the last decade, investment cost reductions of around 20% have been observed for each 50% increase in the total installed capacity of solar water heaters. Combi-systems in particular have benefited from these cost reductions, and have increased their market share. Further RD&D investment can help to drive these costs down further. Cost reductions are expected to stem from:

- direct building integration (façade and roof) of collectors;
- improved manufacturing processes; and
- new advanced materials, such as polymers for collectors.

Furthermore, cost reduction potential can be seen in increasing productivity by the mass production of standardised (kit) systems, which reduce the need for on-site installation and maintenance works.

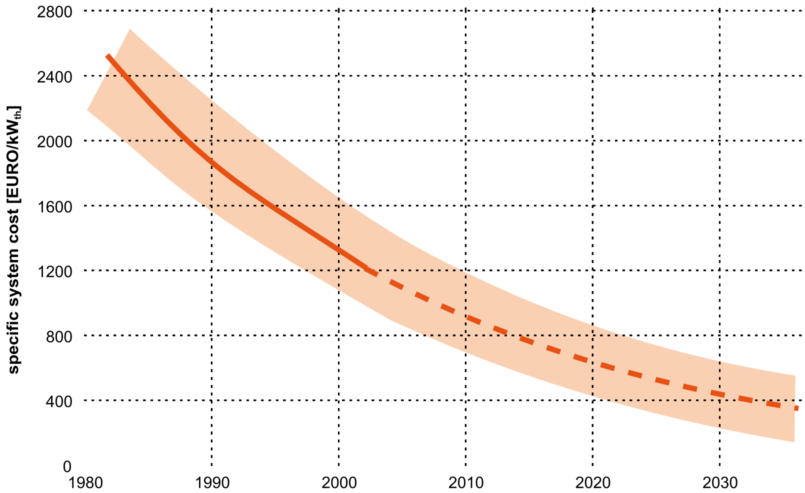


Figure 14: Development of specific costs and installed capacity for small solar thermal systems (forced circulation) in central Europe. (Source: ITW, University Stuttgart)

Advanced applications, such as solar cooling and air conditioning, industrial applications and desalination/water treatment, are in the early stages of development, with only a few hundred of first generation systems in operation. Considerable cost reductions can be achieved if R&D efforts are increased over the next few years.

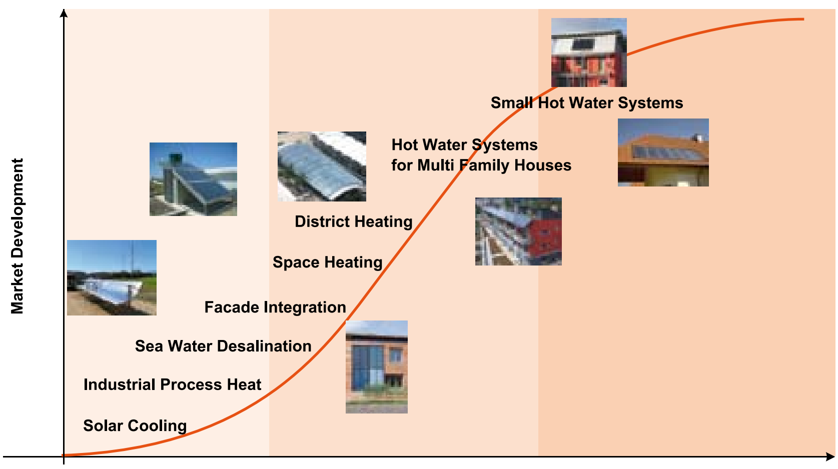


Figure 15: Indication of the current state of deployment of solar thermal applications from development to application in the mass market. (Source: AEE INTEC, 2008)

6.3 Employment

As is the case with other renewable energy industries, solar thermal has become a job motor in Europe. The solar thermal sector in Europe currently provides 28,000 full-time positions in a range of sectors, including manufacturing, marketing, system design and engineering, installation and after sale services. Provided that Europe is able to rapidly increase its share of the global market and expand its domestic market, this figure is expected to increase to 220,000 by 2020.

The following table shows figures for production, turnover and employees for some of the leading European solar thermal manufacturers.

Company	Production		Turnover (EUR million)		Employees	
	Tm^2	Pro-ducts	Total	Solar thermal	Total	Solar thermal
Alanod (DE)	1400	C	n.a.	25 mil EUR	440	35
BBT (DE)	260	FPC, ETC	2800	~ 11% (1)	12900	n.a.
BlueTec (DE)	1100	C	25	100%	20	20
GREENoneTEC (AT)	760	FPC, A, ETC	80	100%	360	360
KBB (DE)	330	A, FPC		100%	65	65
Paradigma/Ritter (DE)	100	ETC		47%	264	160
Schott (DE)	28	ETC	2200	n.a.	6900	150
Schüco (DE)	200	FPC	1600	~ 3%	4700	400 (2)
Solvis (DE)	160	A, FPC	47	48%	120	n.a.
SunMaster (AT)	120	A, FPC	18	100%	83	83
Thermomax (UK)	93	ETC	26	100%	220	220
ThermoSolar (DE/CZ)	200	C, A, FPC	20-25	> 80%	140	120
TiNOX (DE)	480	C	10	100%	20	20
Vaillant (DE)	65	FPC, ETC	2000	~ 5%		n.a.
Viessmann (DE)	345	FPC, ETC	1400	~ 20%	7400	n.a.
Wagner (DE)	170	FPC, ETC	120	40%	250	170
Wolf (DE)	95	FPC	230	25%	1200	40

FPC: flat-panel collectors; ETC: tube collectors; A: Absorber; C: Absorber Coating.
1) Renewables segment overall;
2) ST and PV;
Source: W.B. Koldehoff, August 2007.

Table: Production, turnover and employees for selected European collector and absorber manufacturers in 2006. (Source: Sarasin, 2007)

The table above is by far not complete: There are many more collector and absorber manufacturers in the EU. Within the manufacturing sector, other jobs are created in the supply industries (metal, glass and insulation material), as well as in the component production sector (storage tanks, piping, controllers and transfer fluids). In total, there are about 8,000 full-time positions in the ST manufacturing sector. Most of these jobs are in marketing and distribution, systems design and engineering, installation and after-sales services.

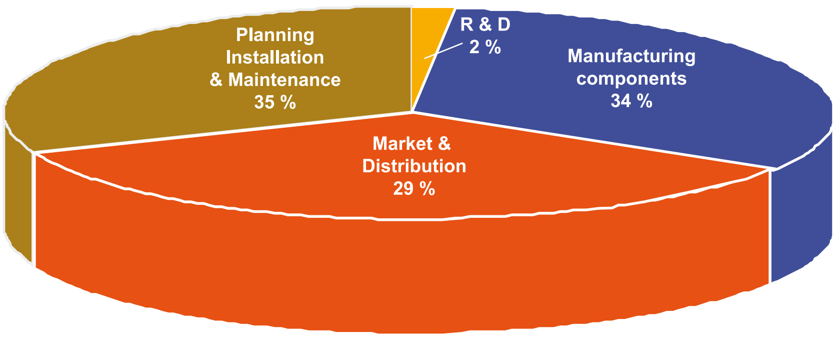


Figure 16: Shares of costs of Solar Thermal systems (small domestic hot water system, forced circulation, estimated EU average). (Source: ESTIF internal survey)

Manufacturing represents limited labour costs, while the orange areas relate mainly to local labour-intensive services.

It is crucial to maintain the technological leadership of European manufacturers, in order to ensure a significant market share of the future global ST market. Global annual sales are currently in the region of 18 GW_{th} (25 million m^2) per year. And the European share of the present global market is only around 15-20%, due to the dominance of the Chinese low tech, low cost demand, which is mainly served by local producers.

To make a projection on future employment rates in the ST sector, it is necessary to make certain assumptions on:

- the global and EU domestic market development;
- the export capacity of the EU ST industry; and
- labour productivity increases.

Assuming an average annual growth rate of 20%, a global market size in the range of 150 GW_{th} (250 million m^2) per year can be projected for 2020. This is a relatively conservative assumption, taking into account that Europe recently experienced higher rates for several years. Whereas North America and other parts of the world have yet to begin serious ST development.

By increasing their technical leadership, European manufacturers could increase their share of the global market from the present 15-20% to 40%. Of course, this largely depends on R&D progress by European companies, compared to global competitors. This assumption is ambitious but feasible, when taking into account an increase in the demand for high-quality European products, which can be expected in North and South America, advancing Asian countries, as well as in Europe itself. This would lead to annual sales by European manufacturers in the range of 70 GW_{th} (100 million m^2); a large percentage of which would be exports. Even making conservative assumptions (very high productivity increases), this would create approximately 220,000 full-time jobs, 100,000 of which would be in manufacturing, and 120,000 in ST services (marketing, distribution, system design, installation and maintenance).

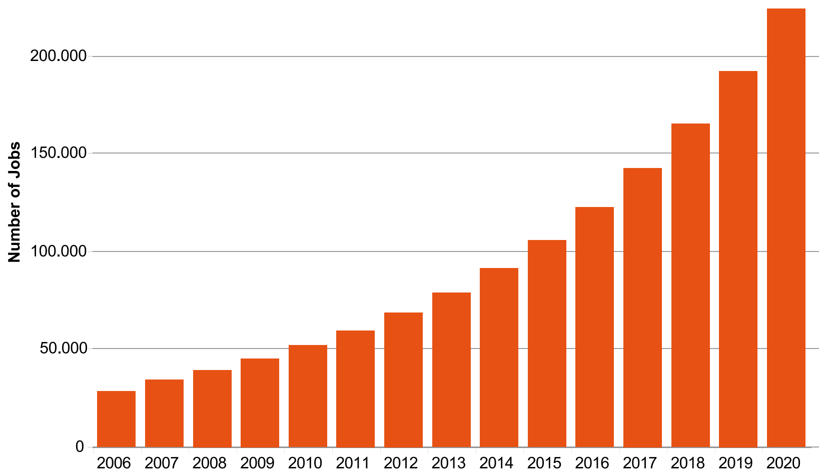


Figure 17: Solar Thermal jobs in Europe. Effects on future employment based on the 20% market growth rates discussed earlier. (Source: AEE INTEC, 2008)

6.4 International competition and technological leadership

Europe is without any doubt the worldwide technological leader in solar thermal development. European companies lead mainly in the following sectors:

- Selective surfaces for absorbers
- Advanced collector production methods (e.g. laser welding)
- Advanced flat plate collector technology
- High quality vacuum tube collectors
- Process heat collectors
- Stratified hot water storage
- Electronic controllers
- System technology (e.g. solar combi-systems with a burner directly integrated into the storage)
- Large-scale ST systems combined with seasonal heat stores
- Advanced applications (cooling, combi-systems and industrial applications)

So, Europe is currently leading in nearly all sectors of ST technology, which explains why the manufacturing capacity in Europe is growing enormously, notably in relatively high-wage countries, such as Austria, Germany, Denmark and the UK.

Moreover, some European countries, including Sweden, Denmark, Germany and Austria are leaders in low-energy building technologies, which are a prerequisite for a high ratio of solar thermal in heating systems. In this area, strong cooperation with other technology platforms, such as ECTP and SusChem, is necessary.

The significant growth seen in the European market over the last decade has helped to consolidate this technological advancement. However, the current market size in Europe (around 2 GW_{th} new installed capacity per year) is still tiny, compared with the current Chinese market (12.6 GW_{th} per year) and the expected future global ST market, which could reach 100-200 GW_{th} within a decade.

However, in the context of such dynamic market growth and technical development, maintaining technological leadership cannot be taken for granted. In order to maintain this European technological leadership, it is crucial for Europe to invest serious money in ST R&D. Internal demand in Europe also needs to grow quickly enough to make it the largest market worldwide (per capita). The ESTTP is playing a crucial role in supporting and meeting both these challenges.

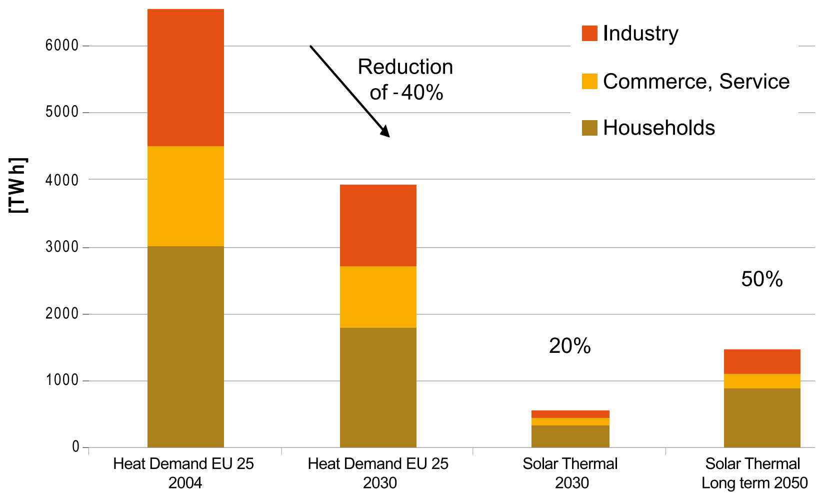
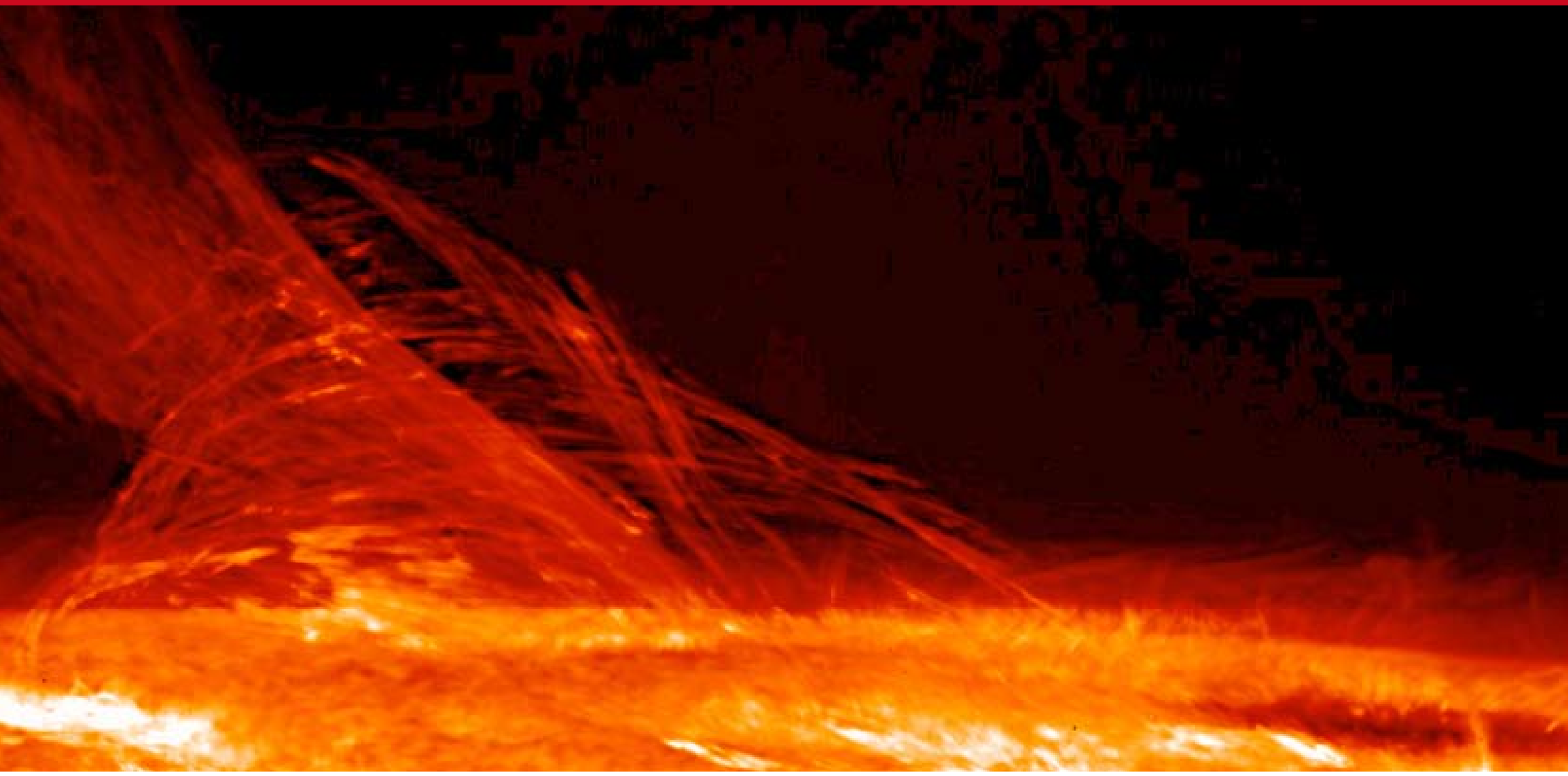


Figure 18: Contribution of solar thermal to EU heat demand by sector, assuming that the total heat demand can be reduced by energy conservation and a 40% increase in efficiency by 2030.
(Source: AEE INTEC, 2008)

This image of the sun reveals the filamentary nature of the plasma connecting regions of different magnetic polarity

Source: http://commons.wikimedia.org/wiki/Image:171879main_LimbFlareJan12_lg.jpg (created by NASA); Author: Hinode JAXA/NASA)



7 Deployment roadmap

7 Deployment roadmap

This chapter outlines a roadmap for the deployment of solar thermal energy towards the implementation of the Vision 2030 discussed above.

The basic principle of solar thermal is always the same, and similar components and technologies are used in all applications. However, there are certain technological and market development challenges. This chapter addresses key areas for the use of solar thermal energy, which include buildings, industrial processes (desalination and water treatment) and district heating. An introduction to each of these sectors is followed by a table giving an overview of the current situation, and the predicted stage of development in 2020 and 2030, taking into account a number of technological and market development parameters.

This Deployment Roadmap serves as the basis for the detailed Strategic Research Agenda, assuring that the proposed research fields are embedded into the requirements arising from expected market needs. The Strategic Research Agenda (see Chapter 8) describes in detail the necessary R&D work.

It is expected that the energy and climate crisis will drastically change the heating market over the next two decades. In new buildings, we expect a tightening of energy performance requirements, including the obligatory use of renewables, which will be increasingly required by governments and the market. In the existing building stock, energy savings will become the key driver for renovations, and district heat operators will become more interested in, and possibly be forced to increase the share of renewables.

For industrial process heat and cooling, the key driver will be the need to reduce growing energy costs, and possibly the cost of emission allowances at the carbon market, as long as they are applied to heat consuming processes.

All these developments will lead to a sharp increase in the use of solar thermal technologies and the subsequent need for new and advanced technologies in this field.

7.1 Towards the active solar building

As seen above, most solar thermal systems are currently dedicated only to hot water production, which has traditionally been the main application for solar thermal. Over the last decade, "Combi-systems," which provide both hot water and space heating, have become a standard product, and have gained a considerable market share in the leading markets of Central and Northern Europe. Typically, the average combi-system covers 70-90% of the hot water demand and 10-20% of space heating demand, depending on a number of external factors.

The ESTTP vision is to establish the Active Solar Building as a standard for new buildings by 2030. Active Solar Buildings cover 100% of their demand for heating (and cooling, if any) with solar energy.

For existing buildings, the aim of the ESTTP is to foster the Solar Active Renovation, achieving massive reductions in energy consumption through energy efficiency measures and passive solar energy. The aim is also to cover substantially more than 50% of the remaining heating and/or cooling demands with active solar energy.

There are already many Active Solar Buildings with a proven track record in Central Europe. In 1989, the first one-family house covering 100% of its heating requirements with solar energy was created in Switzerland. More recently the first multi-family buildings with 100% solar thermal coverage were introduced.

Figure 19: 100% solar heated multi-family house in Switzerland. Installed capacity 193 kW_{th} (276 m² collector area) and a 205 m³ heat storage.
(Source: Jenni Energietechnik AG, Switzerland)

The requirements are high efficiency values, a sufficiently large solar collector area and a seasonal heat storage system, enabling solar energy accumulated in the summer months to be used during the winter.

Heat storage represents a key technological challenge, since the wide deployment of Active Solar Buildings largely depends on the development of cost-effective and practical solutions for seasonal heat storage. The ESTTP vision assumes that, by 2030, heat storage systems will be available, which allow for seasonal heat storage with an energy density eight times higher than water. In other words, to store the same amount of energy, 8 times less volume than water will be required.

For solar collectors, significant improvements are still possible, particularly in terms of cost reductions and design. However, low temperature collectors, which are usually used on buildings, are already very efficient.

High energy efficiency values can be reached through:

- high insulation standards, which reduce losses; and
- optimal architecture, which integrates passive solar measures, such as active windows, shading or ventilation systems.

Furthermore, the productivity of solar thermal systems is enhanced by heating and cooling systems that require a low temperature difference between the supply system and the indoor temperature, such as radiant surfaces, floor heating and cooling, ceiling heating and cooling, and heating/cooling of ventilation air. Most of these solutions already exist, but there is still potential for cost reductions, increased performance and easier integration.

The demand for cooling in buildings is growing dramatically; and not only in Southern Europe. Despite the impressive growth rates, solar assisted cooling is still in the very early stages of development. Over the next decade, the first Solar "Combi+-Systems," supplying domestic hot water, space heating and cooling for buildings will be installed. However, significant R&D must be carried out in order to exploit the potential for further technological development, which will pave the way for the large-scale deployment of solar cooling. These R&D investments will be beneficial for society as a whole, taking into account that solar assisted cooling will replace highly inefficient electrical cooling systems that consume very expensive and polluting electricity at peak times.

7 Deployment roadmap

In the future, solar active systems, such as thermal collectors, PV-panels and PVT-systems, will be the obvious components of roof and façades. And they will be integrated into the construction process at the earliest stages of building planning. The walls will function as a component of the active heating and cooling systems, supporting the thermal energy storage through the application of advanced materials (e.g. phase change materials). One central control system will lead to an optimal regulation of the whole HVAC (heating, ventilation and air conditioning) system, maximising the use of solar energy within the comfort parameters set by users. Heat and cold storage systems will play an increasingly important role in reaching maximum solar thermal contributions to cover the thermal requirements in buildings.

Key areas for technological development

While a very small number of Solar Active Buildings have already been showcased, making them a mainstream building standard by 2030 will only be possible if significant technological progress is achieved in the following areas:

- **High-efficiency solar collectors** will increase the energy gained under winter conditions, while maintaining high levels of durability and increasing the cost-efficiency of the manufacturing and installation process.
- New **compact, time indifferent thermal storage technologies** will significantly reduce the space required for heat storage devices. This will lead to cheaper and more practical seasonal heat storage, allowing large amounts of heat accumulated during the summer to be used for space heating during the winter.
- Improved **solar thermally driven cooling systems** will make it possible to cover much of the rising demand for air conditioning with solar energy.
- **Intelligent control systems** of the overall energy flows in buildings will contribute to a reduction in energy consumption and the optimisation of solar energy usage.

The following tables outline the various scenarios and requirements from now until 2030.

RESIDENTIAL/COMMERCIAL, NEW & EXISTING BUILDINGS		
2008	2020	2030
TECHNICAL		
Fundamental research		
• Orientation stage for Compact Time-indifferent Storage (CTIS) • Orientation to start R&D on new or innovative materials (low cost/ high requirement)	• Second generation compact storage started • Cooling option for domestic purposes reaching conclusion • Full fundamental R&D completed for Compact Time-indifferent Storage • New materials proven to be usable for ST applications • Building integration aimed at integration with building elements and integration with other equipment	• Next generation
Industry developments		
• System development for cooling systems • Combi-systems and system integration • Price/performance optimisation on SDHW-systems • Building integration	• Product development to commercial compact/ time-indifferent storage systems for wide use in combi-systems • Cooling options as integrated units for domestic sector • New materials incorporated in product development (expected impact on cost price/ performance ratio to lead to a 25% improvement) • Greater adaptation to the building sector, further integration with heating systems and roof	• Integrating compact/ time-indifferent storage systems in existing buildings

RESIDENTIAL/COMMERCIAL, NEW & EXISTING BUILDINGS		
2008	2020	2030
Identified demonstration/lighthouses		
• Cooling for 10 kW + systems	• Demo compact heat storage first generation • Third generation combi-system, using CTIS (100% DHW+SH) • High performance renovation; passive house standard for renovation • Plug and play	• Active solar renovation with less than a 75% energy requirement
100% market applicable technologies		
• Solar domestic hot water systems (SDHW) (Solar fraction 50-90%, depending on latitude) • First generation combi-system deployed on a fairly large scale in AT + DE (solar fraction at around 75% for DHW and 10% for space heating)	• SDHW systems • Solar cooling for commercial sector • Solar combis (second generation - DHW 80-90+%, SH 25-50%+ depending on latitude)	• Compact heat storage in 2nd generation in full market deployment. • Cooling for all building types available • Combi systems provide 100 % solar fraction • Combi systems with cooling possibilities • Solar systems integrated with ventilation system, heat pumps etc.
Standards and certification		
• Calculation methods for EPBD through CEN, TC 312, + upgrade of CEN series • Keymark on collectors – widespread systems certification (Keymark) initiated • Installation qualification in some countries	• Combi-systems in Keymark • Standard and certification process for cooling in final stage • Separate standards for CTIS in preparation	• Full standards and certification for all ST applications in new build sector • Certificates based on standards for products and systems on installation quality

RESIDENTIAL/COMMERCIAL, NEW & EXISTING BUILDINGS		
2008	2020	2030
Performance and durability		
• First generation of systems and components have proven 15-25 yrs + life expectancy	• Price/Performance increased overall by 35% check costs figures with new chapter compared to 2007 • Durability proven to be >20 yrs on system level • Add remark on LCA and the need for materials with less environmental impact	• New materials reduced burden on scarcer raw materials • Recycling standard in design of systems • Durability to maintain on 20-25 yrs lifetime expectancy

RESIDENTIAL/COMMERCIAL, NEW & EXISTING BUILDINGS		
2008	2020	2030
MARKET		
Share of solar in different applications and regions		
• <1-50% of SDHW systems in new buildings, depending on local policies (not climate related) • Combisystems- first significant market shares entries in D & Austria • >90% of EU ST market in small buildings (houses for 1-2 families). In a few regions, first significant penetration into new large buildings • Existing buildings: High share only in some regions	• 25-75% of new buildings use SDHW (standard now for all new buildings) • Existing buildings: Penetration of 10% in all Europe. Best regions reach 80% penetration • Combi systems are commonly used in all countries (of which many combine them also with cooling) > 50% of the ST market consists of Combi Systems • Wide use of ST also in large buildings	• All new buildings rely on their heating, cooling and comfort system on integrated solar thermal systems • Integration with building construction and other installation components (like ventilation, heat pumps) are common practice • Buildings without a solar system catch people's eyes: children ask "why doesn't that house have a solar collector?"

RESIDENTIAL/COMMERCIAL, NEW & EXISTING BUILDINGS		
2008	2020	2030
Education of professionals		
• Training programmes are set-up in most countries; however the implementation in the installer sector shows delays. Nr of trained installers is considered too low for market deployment ambition • In most regions, still very low awareness & training among heating engineers, architects. The latter partly still almost hostile • Education in vocational schools and higher education is getting shape	• Solar Thermal is normal part of the curriculum at all levels in education system • Knowledge base at installers level is adequate • Complementary trainings are offered for combi-systems and cooling	• Solar Thermal is normal part of the curriculum at all levels in education system
Regulatory issues		
• After having been neglected for decades, RES-H is now firmly on the EU agenda, with first results in terms of concrete legislation at national and regional levels. Future EU directive will, for the first time, force Member State to set targets that also cover ST • Against the background of new legislation on Energy Performance requirements in new buildings, a few MS implement regulations on energy performances standards to make ST a competitive opportunity, whilst others take further steps to make ST a requirement in new buildings. • Standards: development towards EU-wide acceptance of CEN standards, rather than MS national standards	• EU has driven the regulatory basis for obligations in new buildings and major renovations; at this stage to provide a minimum of 50-100% of domestic water and 25% of space heating / cooling from solar • All systems required to meet CE and Solar Keymark requirements and standards • Energy performance requirements for renovation and obligations in some regions	• Building regulations do not allow the use of external energy sources. All energy needs to be produced on site by renewables • Standards: EU-wide required CEN standards and certification

RESIDENTIAL/COMMERCIAL, NEW & EXISTING BUILDINGS		
2008	2020	2030
Price / Performance		
• Due to rising energy prices, technological progress and effects on economy of scale the P/P ratio has improved and reaches a neutral balance in comparison with most tradition fuels, allowing early adaptors to enter • Guaranteed Solar Result Contracts and other ST-ESCO solutions are offered only by few, peripheral market players	• Lower solar fraction options are all competitive; the higher solar fraction options reach a neutral balance in comparison with most tradition fuels, allowing early adaptors to entry • Guaranteed Solar Result Contracts and other ST-ESCO solutions are standard for medium and large systems, and partly used for small systems, within a context of growing use of ESCOs in buildings	• P/P ratio very competitive compared to traditionally fuelled buildings for heating and cooling. NPV of Renewable energy system show housing cost (including energy) considerably lower compared to living / working in existing building stock. • Guaranteed Solar Result Contracts and other ST-ESCO solutions are standard for all system sizes, within a context of wide use of ESCOs in buildings
Financial support		
• Most countries (>75% of MS) have some sort of financial support, usually around 10-20% of the investment costs	• Financial support schemes no longer needed for SDHW. They remain necessary for very high solar fractions on space heating or cooling and other new market entry technologies during demonstration and market introduction stage	• There is no financial support required
Image and awareness		
• Large differences occur over the various MS. Scattered pattern, depending very much on local market development, public interest and awareness. Overall tendency is that within the RE portfolio: ren. heating is not highlighted; public at large is not aware of large potential	• Solar Thermal is now considered a standard option. No doubt or debate on effectiveness. It is considered a standard and normal technology to make buildings affordable and sustainable	• Solar homes are considered cheaper, more comfortable and provide long term security of energy supply. All attributing to a positive appreciation and acceptance

RESIDENTIAL/COMMERCIAL, NEW & EXISTING BUILDINGS		
2008	2020	2030
Market environment		
• in EP driven markets, ST becomes a competitive option to reach EP-levels • Heating industry has seriously got involved in ST • Construction industry is starting to show interest, particularly but not only in obliged markets	• The building and installation sector have become used to solar thermal. From design to installation the "standard" options are all automatically taken into account	• The technology is considered common and standard

7.2 Industrial process heat, including water treatment and desalination

Solar Heating for Industrial Processes (SHIP) is currently at the very early stages of development. Less than 100 operating solar thermal systems for process heat are reported worldwide, with a total capacity of about 24 MW_{th} (34,000 m^2). Most of these systems are of an experimental nature, and are relatively small scale. However, there is great potential for market and technological developments, as 28% of the overall energy demand in the EU27 countries originates in the industrial sector, and much of this is for heat of below 250°C.

In the short term, SHIP will mainly be used for low temperature processes, ranging from 20 to 100°C. With technological development, more and more medium temperature applications, of up to 250°C, will become market feasible. According to a recent study (Ecoheatcool 2006), around 30% of the total industrial heat demand is required at temperatures below 100°C, which could theoretically be met with SHIP using current technologies, and 57% of this demand is required at temperatures below 400°C, which could largely be supplied by solar in the foreseeable future.

In several specific industry sectors, such as food, wine and beverages, transport equipment, machinery, textiles, pulp and paper, the share of heat demand at low and medium temperatures (below 250°C) is around 60% (POSHIP 2001). Tapping into this potential would provide a significant solar contribution to industrial energy requirements.

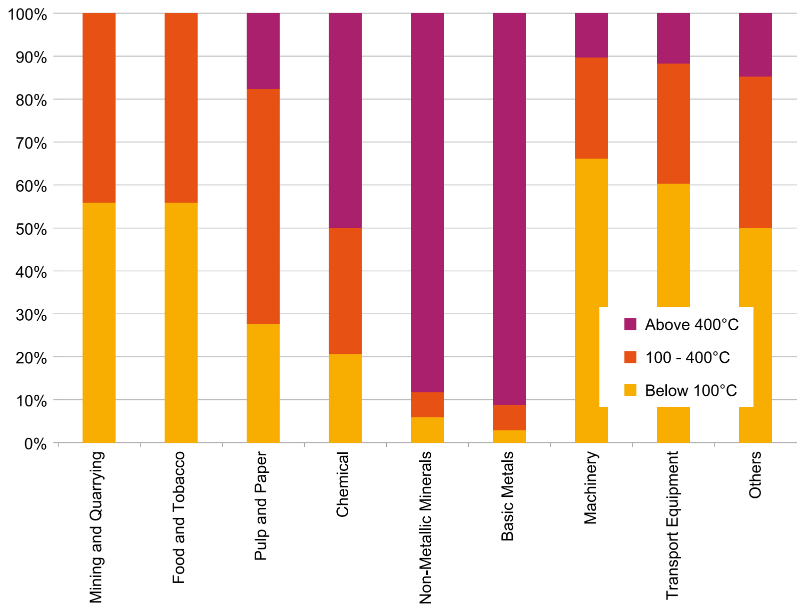


Figure 20: Processes at different temperature levels in different industry sectors; Data for 2003, 32 Countries: EU25 + Bulgaria, Romania, Turkey, Croatia, Iceland, Norway and Switzerland. (Source: ECOHEATCOOL (IEE ALTENER Project), The European Heat Market, Work Package 1, Final Report published by Euroheat & Power)

Substantial potential for solar thermal systems exists in the food and beverages, textile and chemical industries, as well as in washing processes.

Among the industrial processes, desalination and water treatment (such as sterilisation) are particularly promising applications for the use of solar thermal energy, as these processes require large amounts of medium-temperature heat, and are often necessary in areas with high solar radiation and conventional energy costs.

Clearly, the use of Solar Heating for industrial processes should be part of a comprehensive approach, which also takes into account:

- energy efficiency measures;
- the integration of waste heat into processes; and
- a reduction in heating and cooling demand through the use of a heat exchange network.

Key areas for technological development

Since Solar Heat for Industrial Processes (SHIP) is in the initial stage of development, the forthcoming challenges relate to both technology and market deployment. Details of the most important challenges are set out below.

Medium-temperature collectors and components: An ample choice of solar thermal collectors is commercially available for low temperatures (operating temperatures up to around 80-90°C) and for high temperatures (>250°C, mainly used for electricity generation). The development of cost-effective and reliable medium-temperature collectors, which can meet the requirements of most industrial processes, is now required. Other components of solar systems also need to be adapted to this range of temperatures. For example, SHIP would benefit from the development of a new generation of compact and/or seasonal heat storage systems, and from advanced controllers.

Thermodynamic optimisation of processes: Despite the fact that many processes in the industry operate at temperatures below 100°C, the heat supply of most industrial machines is currently provided by steam networks operating at between 140 and 180°C. This makes the use of solar thermal less attractive, or even impossible.

Switching to lower temperatures would imply significant investment for infrastructure (network) modification and process redesign, which reduces the attractiveness of solar energy. New technologies can be developed, which allow processes to operate at lower temperature. One example is the reduction of bath temperatures in pickling plants. In some cases, processes can also be efficiently redesigned to make them more compatible with the daily and/or seasonal cycle of solar energy supply. Moreover, when new, long-term industrial process facilities are planned, there is always the possibility of subsequent solar add-ons.

Integrating solar thermal into industrial processes will be a complex process, requiring support from energy agencies and other public players, dedicated to specific industrial sectors.

Need for dedicated design guidelines and tools: Currently only a few engineering offices and research institutes have experience with SHIP installations. Planning guidelines and tools for typical industrial uses need to be made available to a wider community of SHIP-experienced engineers. This would mean that:

- other potential users could be offered a SHIP solution;
- system design costs would fall; and
- the broader experience would increase the effectiveness of SHIP systems.

Investment costs: Solar systems are capital intensive, as costs are mainly upfront. Industrial companies often optimise their processes with short-term ROI expectations that cannot currently be met by SHIP systems. The wide market development of SHIP would also require dedicated financing and contracting solutions; the lack of which is currently an important barrier to growth. It is crucial, therefore, to rapidly create a market, in order to reach the minimal critical mass required to start benefiting from economies of scale.

While RD&D can increase potential and reduce costs in the medium term, financial incentives and widespread public-funded demonstration projects are an absolute necessity.

Applied research is necessary in a number of fields, including:

- stagnation behaviour and management of large collector fields;
- monitoring of SHIP systems; and
- system optimisation methodologies, to enhance the interaction of solar energy, heat recovery and conventional energy sources in various industrial processes.

Due to their relevance and specific technological requirements, desalination and water treatment are discussed in a separate overview table on the right:

<table>
<tr><th colspan="3">INDUSTRIAL SECTOR, PROCESS HEAT</th></tr>
<tr><th>2007</th><th>2020</th><th>2030</th></tr>
<tr><th colspan="3">TECHNICAL</th></tr>
<tr><th colspan="3">Fundamental research</th></tr>
<tr><td>• Collectors and systems for temperature levels of 80-250°C
• R&D on new/innovative materials and concepts for heat storage (such as latent heat and phase-changing materials)
• R&D on heat storage for temperature > 100°C
• Simulation tools for planning SHIP systems</td><td>• R&D for storages > 100°C
• New materials that can be used for ST applications
• Collectors and systems for high temperature levels (> 250°C)</td><td>• Next generation</td></tr>
<tr><th colspan="3">Development in industry</th></tr>
<tr><td>• Solar Thermal Collectors with operating temperatures of 80-250°C
• Systems with water, thermal oils, steam and air
• Double glazed collectors and anti-reflective-glass
• Parabolic collectors and CPC collectors</td><td>• Product development for heat storages
• Standardisation of system concepts
• Solutions for stagnation problems in big systems
• Solar roofs for industry buildings</td><td>• Next generation</td></tr>
<tr><th colspan="3">Identified demonstration/lighthouses</th></tr>
<tr><td>• Systems for hall heating, drying processes, washing and brewing - system size: a few hundred kW
• Systems for cooling e.g. winery</td><td>• Large systems with high temperature heat storages
• Large systems of more then 2000 kW
• Plants in all industry sectors (food and beverage, textiles chemicals) and different applications (washing, drying, boiling, pasteurising and heat treatment)</td><td>• 100% solar heated plants and factories in each industry sector (operation temperature < 250°C)
• SHIP for applications that require high temperatures (> 250°C)</td></tr>
</table>

INDUSTRIAL SECTOR, PROCESS HEAT		
2007	2020	2030
100% market applicable technologies		
• CPC Collectors 80-120°C • Flat plate collectors 80-150°C • Vacuum tube collectors • Systems for processes up to 80°C	• Collectors with high efficiency for operating temperatures up to 250°C • Solar cooling/heat recovery for building sector (industry halls and office buildings) • Methods for the integration of solar heat into each industry sector's main processes • Methods for energy efficient processes at lower temperature levels and heat recovery • Monitoring, measurement and simulation software	• It is normal in process engineering to build a SHIP system for each process with temperatures < 250°C
Standards and certification		
• Keymark on collectors	• Standard & certification process for low&medium temperature systems in final stage	• Full standards and certification for all ST application in process heat sector
Performance and durability		
• Long experience at low temperature levels (< 100°C). First generation systems and components have a proven life expectancy of 15-25 yrs +	• The monitoring of systems that have been running for many years shows that there is no significant reduction in performance	• New materials reduced burden on scarcer raw materials

INDUSTRIAL SECTOR, PROCESS HEAT		
2007	2020	2030
MARKET		
Share of solar in different applications and regions		
• Worldwide installed capacity of about 27 MW_{th} (38,500 m²) • About 85 solar thermal plants with SHIP worldwide	• 4 GW_{th} (5.7m m²) installed capacity in EU27 for low temperatures (<100°C) • 0.4 GW_{th} (570,000 m²) installed capacity in EU27 for medium temperatures (100-250°C)	• 15 GW_{th} (21m m²) installed capacity in EU27 for low temperatures (<100°C) • 2 GWth (2.85m m²) installed capacity in EU27 for medium temperatures (100-250°C)
Education of professionals		
• No special training programs available; only regional activities, events or workshops • No knowledge in process engineering of integration of solar heat	• Planning guidelines for all applications for SHIP are standard in education for process engineers • Courses for installers and plant constructors are available	• Solar Thermal is a standard part of the curriculum at all levels in the education system • SHIP is standard in the education of installers and plant constructors • SHIP courses are available at university
Regulatory issues		
• Not yet	• All systems required to meet CE and Solar Keymark requirements and standards	• Renewable energy laws oblige the industry to use SHIP for a minimum share of required energy
Price / Performance		
• Company decision makers expect 3-5 years amortisation time • New ST-ESCO solutions are offered by only a few companies	• New business models are offered on the markets (guaranteed solar yields and contracting)	• Price/performance ratio is very competitive compared to traditionally fuelled processes for heating and cooling • Guaranteed Solar Result Contracts and other ST-ESCO solutions are standard for all system sizes, within the context of a widespread use of ESCOs in buildings

INDUSTRIAL SECTOR, PROCESS HEAT		
2007	2020	2030
Financial support		
• Only a few special regional support programs for building SHIP systems, for example, Austria/Upper Austria • National support programs for R&D	• Financial support schemes for SHIP • Support schemes for demonstration projects • Support for R&D projects	• No financial support required
Image and awareness		
• Solar process heat is an unknown technology. There are only a few companies focused on offering systems for solar process heat	• Decision makers in all relevant industry sectors know about SHIP possibilities • Lighthouse projects and best practise systems inspire confidence in the new technologies • Image campaigns and information for SHIP	• Solar plants are considered cheaper, more comfortable and provide long-term security of energy supply. This all contributes to a positive image and acceptance
Market environment		
• There is no demand from consumers or industry. Finished projects are demonstration projects driven by the R&D sector • Process technology does not consider the requirements for solar thermal process heat • Industrial processes are not always energy efficient (supply temperature is on high temperature level with no heat recovery)	• Companies are offering turn-key SHIP systems in cooperation with plant constructors • Trade fairs for SHIP bring this technology to industry decision makers • Plant constructors have specialised SHIP departments	• The technology is considered common and standard for plants • Solar Thermal is the main heat source for processes < 250 °C in new build factories.

DESALINATION and WATER TREATMENT		
2007	2020	2030
TECHNICAL		
Fundamental research		
• R&D on new/innovative materials (low cost/ high requirement) for efficient thermally-driven heat and mass transfer (evaporation and condensation) • Efficiency increase of solar power generation for desalination purposes • Polymer science (functional material foils and fabrics, heat conducting polymers) - market research • Multi-water quality generation; combination of desalination methods • Multi-stage desalination; salt production; high recovery - 30 to 50% • Develop low cost and robust concept for easy technology transfer	• R&D on new/innovative materials (low cost/ high requirement) for even more efficient thermally-driven heat and mass transfer (evaporation and condensation) • Oil-free plastic heat transfer materials condenser • R&D on system design and system components • Polymer science (functional material foils and fabrics, heat conducting polymers) - market research • Material research for high temperature (rather "medium temperature" or "elevated temperature") plastic materials • Chemical free brine disposal	• Oil and metal free plastic materials for high performance and durability at low cost • Direct solar thermal water evaporation with integrated heat recovery (large-scale CSP&W) • New desalination processes

DESALINATION and WATER TREATMENT		
2007	2020	2030
Development in industry		
• Easy and maintenance free water pre-treatment for thermal desalination, without fouling and scaling formation • Envisaged: efficiency increase of thermal processes depending on the capacity • System design for small applications • Cost efficient, integrated transport casing designs	• House integrated building designs; desalination becomes part of house technology • Easy-to-build and to maintain systems for decentralised, small-scale applications without the need for external power supply (electricity, fuels) • New solar collectors and storage adapted to the needs of solar desalination systems: mid temperature (90-150°C - suitable for high resistance against the aggressive seaside conditions) • Combination of solar thermal desalination and power generation • Multi-stage desalination, using several linked processes to increase recovery by up to 65%	• House of the future: design includes solar thermally-driven components • Grey water recycling and sea water desalination are standard components of any building

DESALINATION and WATER TREATMENT		
2007	2020	2030
Identified demonstration/lighthouses		
• About 10 installed plants with small scale solar desalination (1 to 50 m³ per day)	• 100 installed demonstration plants of small (1 to 50 m³ per day) and larger systems (50-500 m³ per day) • First installations of solar power generation and thermal desalination	• Small networks of renewably driven water distribution systems (for communities of up to 50,000 people) • Highly efficient solar thermal power plants with cooling and desalination
100% market applicable technologies		
• Autonomous systems up to 10 m³ per day	• Systems up to 50 m³ per day	• Large variety of small 1-200 m³ per day (standard), medium (150-2000 m³ per day) and large (1500–20000 m³/day) are ready for the market
Standards and certification		
• Solar Keymark on collectors	• Standard for the design of systems up to 50 m³ • Energy labels for efficient desalination technologies	• Full standards and Full standards and certification for all components in a desalination system • Certified procedures for system integration
Performance and durability		
• First generation of systems and components have proven 15-25 years + life expectancy	• Performance increased by 5-10% • Durability proven to be >20 yrs on system level	• Price/performance reduced by another 15-25% • Recycling procedures for all types of systems • Durability to maintain on 20-25 yrs lifetime expectancy

DESALINATION and WATER TREATMENT		
2007	2020	2030
MARKET		
Share of solar in different applications and regions		
• Only a handful of installations	• 2000 systems are installed in affected areas	• Solar desalination is used in all affected regions to provide drinking water
Education of professionals		
• Systems are sold turnkey. Training is provided by the suppliers	• Planning guidelines for solar desalination are standard in education for process engineers • Courses for plant constructors are available	• Solar thermal is a fixed part of the curriculum • Solar desalination is standard in the education of plant constructors • University courses are available
Regulatory issues		
• Not yet	• All systemsare required to meet CE and Solar Keymark requirements and standards • - 25% share of renewable energy supply for all new installed small and large desalination units obligatory	• CEN-standards and certification is required
Price / Performance		
• Guaranteed Solar Result Contracts and other ST-ESCO solutions are offered by only a few, peripheral market players	• Price/performance reduced by 15-35% depending on system type	• Guaranteed Solar Result Contracts and other ST-ESCO solutions are standard for all system sizes, within the context of widespread use of ESCOs in buildings
Financial support		
• No grants for solar desalination available • Implementation of grants for desalinated water produced by solar or renewable energy	• Grants for solar share in desalination (CO2-emissions trading, extra grant for solar heat in industrial processes (including desalination)	• There is no financial support required

DESALINATION and WATER TREATMENT		
2007	2020	2030
Image and awareness		
• Unknown technology	• Solar Thermal fuel saver mode now considered a standard option • Autonomous state-of-the-art small desalination systems	
Market environment		
• Construction industry is starting to show interest	• House of the future: design includes solar thermally-driven components, especially desalination and cooling	• The technology is considered common and standard

7.3 District heating and cooling

Currently, around 9% of the total heating needs in Europe are covered by block and district heating systems. This share is much higher in a number of countries, especially Eastern Europe and Scandinavia.

Within district heating systems, solar thermal energy can be produced on a large scale and with particularly low specific costs, even at high latitudes, such as in Sweden and Denmark. Only a very minor share (less than 1%) of the solar thermal market in Europe is linked to district heating systems, but these systems make the most of large-scale solar heating plants.

The table below lists the largest solar heating plants (>2 MW_{th}) in Europe - all of them are connected to district heating networks.

Plant, Year in operation, Country	Coll.area [m^2]	Size [MW_{th}]
Marstal, 1996, DK	18 300	12,8
Kungälv, 2000, SE	10 000	7,0
Braendstup, 2007 DK	8.000	5.6
Strandby, 2007 DK	8.000	5.6
Nykvarn, 1984, SE	7 500	5,2
Graz (AEVG), 2006, AT	5 600	3,9
Falkenberg, 1989, SE	5 500	3,8

Plant, Year in operation, Country	Coll.area [m²]	Size [MW_{th}]
Neckarsulm, 1997, DE	5 470	3,8
Crailsheim, 2003, DE	5 470	3,8
Ulsted, 2006, DK	5 000	3,5
Ærøskøping, 1998, DK	4 900	3,4
Friedrichshafen, 1996, DE	4 050	2,8
Rise, 2001, DK	3 575	2,5
Ry, 1988, DK	3 040	2,1
Hamburg, 1996, DE	3 000	2,1
Schalkwijk, 2002, NL	2 900	2,0
München, 2007, DE	2 900	2,0

Together, these systems account for less than 0.5% of EU installed solar thermal capacity. However, their combined capacity is higher than that of 25,000 small solar domestic hot water systems.

The prevalence of Scandinavian countries is surprising, since solar radiation is lower in this region. Central and Eastern European countries and district heating systems in Southern Europe offer much better conditions.

Typical operating temperatures range from low (30°C) to high (around 100°C) for water storage. The majority of plants are designed to cover the heat load over the summer months (hot water and heat distribution losses) using diurnal water storages. However, some are equipped with seasonal storages and cover a larger part of the load. The seasonal storages comprise water in insulated tanks (above or below ground) in ten plants, the ground itself in seven, aquifers in two and a combination of ground and water in another. More than 80% of the plants are equipped with flat-plate collectors, mostly large-module collector designs. Most plants also have pressurised collector systems with an anti-freeze mixture - usually glycol and water - while a few plants in the Netherlands have drain-back collector systems.

Several solar district heating systems, especially in Sweden and Denmark, have ground-mounted collector arrays. This can be a very cheap solution, when surfaces are available and solar is connected to a network serving existing buildings.

Figure 21: Marstal (DK) 12.9 MW_{th} capacity (18,365 m² collector area), integrated into the local district heating system. The world's largest solar thermal plant provides 30% of the total heat demand of a Danish island.
(Source: Arcon Solvarme A/S, Denmark)

In 1995, the district heating operator in Marstal, on a small Danish island, installed around 8,000 m² solar collectors and a 2,100 m³ water storage tank to cover up to 15% of their annual heating load. The plant was later extended to 18,300 m² (12,8 MW_{th}) and is so far the largest solar heating plant in the world. A recent study of the future potential for solar district heating in Denmark has resulted in two new plants of 3.5 and 5.6 MW_{th}.

In Germany, and Austria, roof-integrated or roof-mounted solar collectors, placed on residential or service buildings, are often used.

Figure 22: Solar block heating in Neckarsulm, DE.
(Source: Stadtwerke Neckarsulm and STZ-EGS, Germany)

In the 1980s, Swedish housing company, EKSTA Bostads AB, pioneered the use of roof-integrated solar collectors in new building areas. At present, EKSTA owns and operates about 7,000 m² of roof-integrated collectors. Initially, EKSTA used site-built collectors, but the latest development, a roof module collector mounted directly on the roof trusses, has been used recently in new and existing buildings. This development has resulted in a superior integration into the building process, as well as reduced investment costs and improved thermal performance.

The German large-scale solar heating plants are mainly applied in new residential building areas, using roof-integrated or mounted collectors. Some of the large projects have so-called "solar roofs". Until 2003, eight projects with seasonal storage and around 50 large to medium-scale projects, with short-term storage, had been completed within the Solarthermie2000 programme. In Neckarsulm (Figure 20) and Crailsheim, there are two plants with >5,000 m² of roof-integrated collectors and in Munich, a new plant with 2,900 m² has been constructed.

The first large-scale solar plant in Austria – a small local biomass-fired heating plant complemented with a solar system - was built in Deutsch-Tschantschendorf in 1995. Graz is now the large-scale solar city of Austria. The first plant, built in 2002 (See Figure 23), and two newer plants, the largest with >5.000 m², are connected to the district heating network.

Figure 23: Solar district heating plant in Graz, AT.
(Source: S.O.L.I.D. Solarinstallation und Design GmbH, Austria)

The most widely implemented application of large solar heating systems in The Netherlands is collective housing, institutions and homes for the elderly. Most systems have about 100 m² of solar collectors, but some are larger, for example, the "Brandaris" building in Amsterdam, which has 700 m² of rooftop mounted collectors. Two large-scale plants are designed with seasonal storage, one is a recent plant with 2,900 m² of solar collectors connected to an aquifer storage in Schalkwijk. There are also solar block heating plants in France, Switzerland and Poland.

Key areas for technological development

In the short term, the broader use of solar energy within district heating (and cooling) systems is mainly a question of policy, namely, incentives, regulation, and the demonstration of existing technologies. In the medium and long term, considerable R&D efforts are needed to utilise the full potential of large-scale solar systems linked to district heating.

The need for basic and applied research is mainly related to the development of durable and cost-effective (plastic) liners and water resistant insulation materials for long-term (seasonal) storages. Basic and applied research is also required, related to the further development of large-scale solar collectors, as well as dedicated control devices and optimisation strategies.

DISTRICT HEATING		
2007	2020	2030
TECHNICAL		
Fundamental research		
• Orientation stage for Compact Time-indifferent Storage (CTIS) • R&D on new/innovative materials (low cost/ high requirement) for solar collectors and storages is starting • R&D on absorption and adsorption cooling processes	• Second generation compact storage concepts • New materials for collectors and storages • Absorption and adsorption cooling processes	• New materials for collectors and storages
Developments in industry		
• Large module collectors for roofs and ground • Building-integrated solar collectors • Various cooling machines • Seasonal storage concepts by (contractors)	• Second generation large module collectors for roofs and ground • Second generation building-integrated solar collectors • Second generation cooling processes • Second generation seasonal storages concepts (contractors) • Compact storage systems (new industry)	• Next generation solar collectors, storages and cooling systems
Identified demonstration/lighthouses		
• Block and district heating systems with diurnal and seasonal storage for new and existing buildings • Solar block cooling systems for new buildings	• Solar district cooling • Systems with compact storage concepts	• New concepts

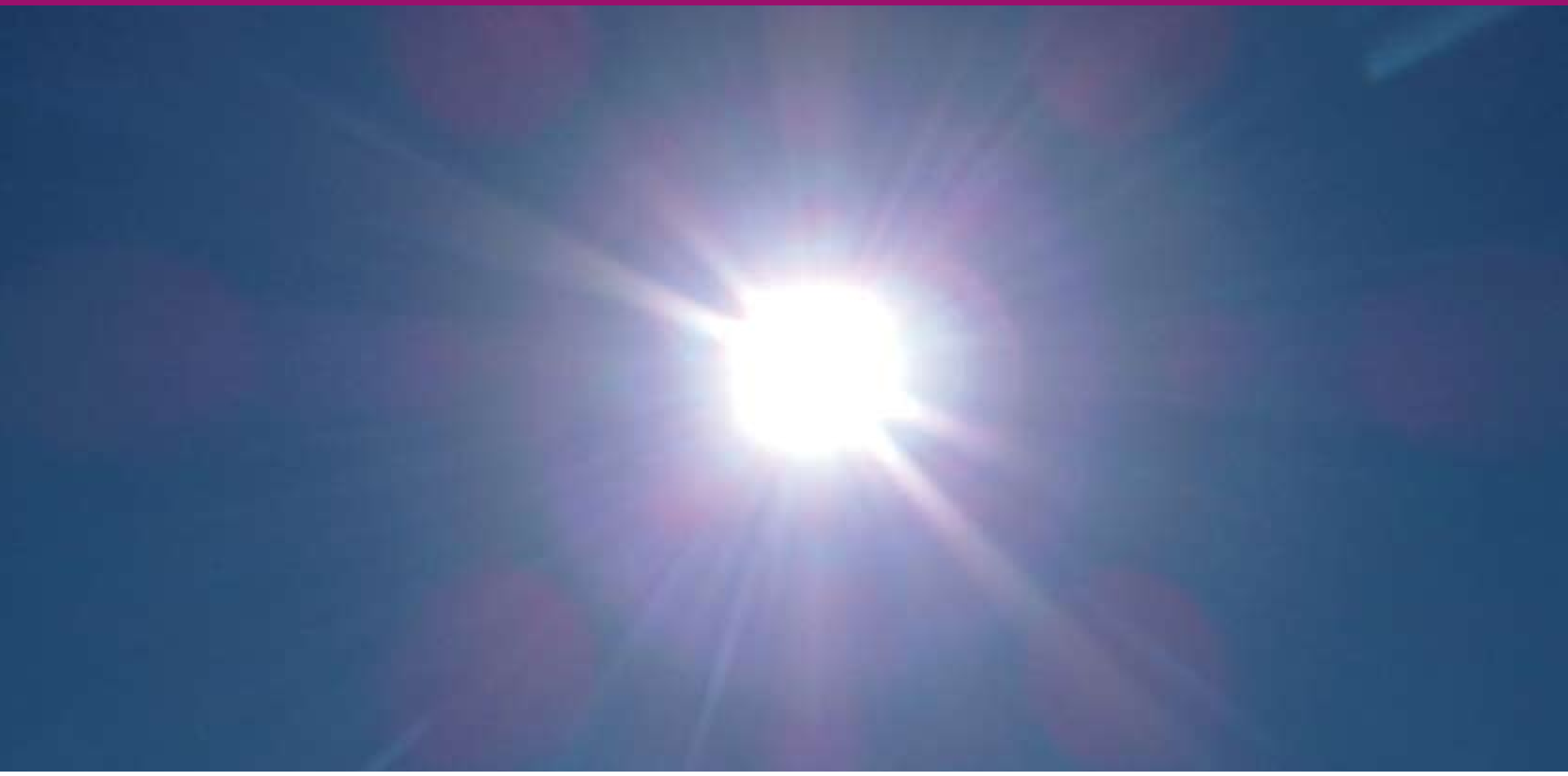
DISTRICT HEATING		
2007	2020	2030
100% market applicable technologies		
• Solar block heating systems with collectors on flat roofs and diurnal storages • Solar district heating systems with ground collectors and diurnal storages	• Block and district heating systems with diurnal and seasonal storages for new and existing buildings • Solar block cooling systems for new buildings	• Compact storage systems • Second generation systems of all sizes • Solar district cooling
Standards and certification		
• Solar Keymark on collectors	• Standards for the design of large systems	• Full standards and certification for all solar district heating and cooling
Performance and durability		
• First generation of systems and components with a proven life expectancy of 15-25 yrs +	• Performance increased by 5-10% • Durability proven to be >20 yrs on system level	• Price/performance reduced by another 5-10% • Recycling procedures for all types of systems • Durability to maintain on 20-25 yrs lifetime expectancy

DISTRICT HEATING		
2007	2020	2030
MARKET		
Share of solar in different applications and regions		
• Solar delivers only 0.1% of total district heating • The market for solar in district heating is 1% of the total solar market	• Solar delivers 1% of the total district heating	• Solar delivers 10% of the total district heating • Solar district cooling is included in 10% of solar district heating systems
Education of professionals		
• Systems are sold turnkey. Training is provided by the suppliers		• Solar thermal is a fixed part of the curriculum

DISTRICT HEATING		
2007	2020	2030
Regulatory issues		
• Standards: development towards the EU-wide acceptance of CEN-standards instead of MS national standards	• All systems required to meet CE and Solar Keymark requirements and standards	• CEN-standards and certification is required
Price / Performance		
• Guaranteed Solar Result Contracts and other ST-ESCO solutions are offered by only a few, peripheral market players	• Price/performance reduced by 15-35%, depending on system type	• Price/performance very competitive compared to traditionally alternatives
Financial support		
• Most systems are built with some financial support	• Financial support schemes no longer needed for systems without storage or with short-term storage. They remain necessary for market entry technologies, e.g. compact seasonal storage, during the demonstration and market introduction stage	• No financial support is required
Image and awareness		
	• Solar Thermal is now considered a standard option	
Market environment		
• Construction industry is starting to show interest		• The technology is considered common and standard

The Sun, as seen from the surface of Earth through a camera lens.

Source: http://de.wikipedia.org/wiki/Bild:The_sun1.jpg
(GNU Free Documentation license)



8 Strategic Research Agenda

8 Strategic Research Agenda

In the Deployment Roadmap above, we have considered the different broad areas of application of solar thermal from a market point of view. The Strategic Research Agenda, however, takes an industrial and technological approach, looking mainly at single components, such as collectors, thermal storages, cooling machines, multi-functional components and control systems. A more holistic approach is used in the case of solar cooling and water treatment (desalination), as these specific applications imply a number of technological questions that must be solved in a coherent manner.

Each chapter, which is the result of the collective work of a number of specialists from industry, research and test institutes offers:

- a detailed analysis and perspective on technological development;
- formulate a specific research agenda; and
- outline a timetable for its effects.

8.1 Solar thermal collectors

Solar thermal collectors are all technical systems, which convert solar radiation into heat.

Low temperature applications (<80°C) are by far the most common, typically involving domestic hot water preparation and space heating. Glazed flat plate and vacuum tube collector systems currently dominate this market. Other technologies are also available, such as unglazed collectors (for very low temperature applications, such as swimming pool heating) and fully CPC type stationary concentrators.

At the **high temperature** end (>250°C), several high concentration technologies are already available on the market. These are mainly used for electricity production through thermal cycles (high concentration parabolic troughs, Fresnel concepts, solar towers and paraboloids). However, this temperature range is largely outside the scope of this report, since the ESTTP focuses on thermal applications rather than electricity generation.

Between these two temperature ranges, there is great potential for many new applications in the **medium temperature** range. This is relevant for buildings (due in particlar to thermally driven cooling technologies, which require heat at temperatures up to 120ºC for single effect systems and 160-180ºC for more efficient cycles), process heat, including various industrial processes, as well as desalination and water treatment. Currently, there is a lack of commercially available collectors suitable for the medium temperature range.

The potential evolution of existing technologies to provide collectors for the medium temperature range includes advanced flat plate collectors, evacuated tube collectors, stationary or quasi-stationary CPC type collectors and low concentration tracking linear parabolic or Fresnel collectors. Some companies are now developing products for this range, however major R,D&D efforts are still required in these areas.

8.1.1 Low temperature collectors

8.1.1.1 Technology status

Flat plate collectors dominate the European market, with more than 2 millions m²/year installed (approximately 85% of the market). Due to the different application modes, including domestic hot water, heating, preheating and combined systems, and due to varying climatic conditions, a number of different collector technologies and system approaches have been developed.

In some parts of the production process, such as selective coatings, the market has developed to industrial large-scale production. A number of different materials, including copper, aluminium and stainless steel, are applied and combined with different welding technologies to achieve a highly efficient heat exchange process in the collector. The materials used for the cover glass are structured or flat, low iron glass. The first anti-reflection coatings are coming onto the market on an industrial scale, leading to efficiency improvements of around 5%.

The improved characteristics of collectors can lead to higher stagnation temperatures, up to 250°C. This should not be confused with the application temperature, which remains in the range of 80°C. Such increased stagnation temperatures require the availability of temperature resistant back insulation materials and heat transfer fluids. Typically, water-glycol mixtures are used, but water systems are coming onto the market with different frost protection technologies. Another heating option is with solar air collectors, which are used mainly for the preheating of air in industrial buildings.

Flat-plate collectors can be installed as single modules on roofs, can be manufactured in a larger format for roof integration and, for facade integration, where a standard exists. Flat-plate collectors can also be installed as large modules on ground and on flat roofs. Nonevacuated CPC collectors are available with very low concentration values; they can even operate in thermo siphon systems, with higher concentration at higher temperatures. However, the increase in concentration involves a number of unresolved issues, including the control of stagnation temperature and the durability of materials.

Vacuum tube collectors make up roughly 10-15% of the European solar thermal market, varying from country to country. In general, the vacuum tube collectors are more efficient, especially for higher temperature applications. The production of vacuum tube collectors is currently dominated by the Chinese Dewar tubes, where a metallic heat exchanger is integrated to connect them with the conventional hot water systems. In addition, some standard vacuum tube collectors, with metallic heat absorbers, are on the market. New European vacuum tube collector producers are also appearing on the market.

As for improved flat plate collectors, it must be ensured that vacuum tube collectors can withstand stagnation temperatures. Dewar type vacuum collectors can be mass produced on a large scale at low cost. However, quality levels need to be monitored and maintained, especially related to long-term durability. There are now some initial ideas on how to integrate vacuum tubes into facades, but there is currently no standard technology available. Vacuum tubes could also be combined with low concentration optics (CPC type or other), creating a new family of collectors, which might be very efficient at temperatures ranging from 100ºC to 180ºC.

8.1.1.2 Potential and challenges for technological development

At present, low temperature collectors are widely used. There are also many other high quality products on the market, which follow different approaches, depending on climatic conditions and applications.

However, in view of the anticipated market development, a number of technological challenges are arising. Some of the key issues include cost reduction, higher quality, aesthetics and building integration.

With regard to cost reduction, the basic trade-off between cost and quality (performance, durability, recyclability and aesthetics) need to be considered. The bulk of the European market has evolved towards higher quality products and systems, but this has not been the case elsewhere (for example, in China, which accounts for more than two thirds of global sales). Looking at the European market, there is ample potential to develop cheaper products, which may be less durable and effective, but which are cheaper and can be easily replaced. This may lead to a different approach, which could be advantageous if lower performance is compensated by lower costs and thus a faster uptake of solar thermal energy use.

Building integration is relevant for both new and existing buildings. It includes issues such as the:

- inclusion of solar collectors in pre-fabricated roofs, awnings and facades; and
- further development of collectors conceived for vertical uses (facades), including large area facade-integrated collectors, which can be combined with so-called active walls or with photovoltaic modules.

Higher levels of building integration require new rounds of RD&D efforts, in close interaction with architects, construction companies and manufacturers of building envelopes.

A related issue is collector size, which is traditionally relatively small (around $2m^2$). However, there is a recent trend towards larger collector sizes, implying a different set of conditions for collector design, manufacturing, logistics and installation. In this area, there is significant potential for technological development. Taking into account the projected rapid increase in market size, the recycling potential of materials used in the solar collectors will be a major issue. The lifecycle assessment of the whole solar thermal system, taking into account the energy fuels and the materials they replace, will also be crucial. And the role of new approaches, such as the active wall concept that heats and cools the room behind it, are very promising and should be developed.

For all issues mentioned in this chapter, specific RD&D attention should be given to air and vacuum tube collectors. Although air collectors have great potential, particularly for applications such as space heating, ventilation and space cooling through ventilation, they are less developed than liquid based collectors. For vacuum tube collectors, the potential for further development lies mainly in improved building integration. This includes easier tube replacement in case of failure, resistance to stagnation, possible thermal improvements and longevity.

Clearly, a major issue is the automation of manufacturing processes, particularly for collector construction, where there still is great potential for increased productivity.

Major efforts are needed in the following areas:

- More efficient ways to use conventional collector materials (metals, glass, insulation), especially with a view to developing multifunctional building components, which also act as an element of the building envelope and a solar collector.
- Evolution in the optical properties of collector components. In particular, a more systematic use of optical films to enhance heat/light transmission in glass covers and reduce this transmission during excessive exposure; and the use of colours in absorbers or covers to achieve more flexible integration concepts.
- Alternative materials for collector production: the use of polymers or plastics, the coating of absorbers optimised to resist stagnation temperatures and new materials to tackle deterioration resulting from UV exposure.
- Improvement in the recycling potential of collector components and materials in view of lifecycle cost reduction, and overall sustainability of materials.

Special topics will include issues such as:

- The control of solar energy delivered by entire facades, in particular the aspects related to fault detection and the consequences of stagnation temperatures when a prolonged no-load situation coincides with peak solar radiation;
- New component testing and evaluation methods; and
- A dedicated concept for the automation of manufacturing processes and assembly techniques.

8.1.2 Process heat (medium temperature) collectors

8.1.2.1 Technology status

Some process heat applications can be met with temperatures delivered by "ordinary" low-temperature collectors, namely from 30 to 80°C. However, the bulk of the demand for industrial process heat requires temperatures from 80°C up to 250°C.

Process heat collectors are a new application field for solar thermal heat collectors. Typically, these types of systems require a strong capacity (and therefore large collector areas), low costs, and high reliability and quality.

While low temperature and high temperature collectors are offered in a dynamically growing market, process heat collectors are at a very early stage of development and there are no products available on an industrial scale.

The technological approaches for process heat collectors can be grouped according to the concentration ratio or the tracking mode. Optical concentration is a way to achieve higher operation temperatures, by reducing the absorber area with respect to the aperture area. The drawback is that concentration reduces the angular acceptance of the aperture area, which means the collector's orientation needs to be adjusted towards the sun. This adjustment is usually seasonal for low concentration ratios, while more frequent adjustments are required for higher concentration ratios. Tracking involves additional mechanical structures with moving parts, which imply additional costs and maintenance needs.

In addition to these "concentrating" collectors, improved flat collectors with double and triple glazing are currently being developed, which might be interesting for process heat in the range of up to 120°C.

8.1.2.2 Potential and challenges for technological development

Increasing the temperature of the heat delivered, while keeping the collector efficiency above 50% is quite a challenge, and requires major RD&D efforts, from industry and the academic world. In this respect, efforts are already underway, but there is still a long way to go.

Initial RD&D efforts will be directed towards the:

- control of heat loss; and
- maximisation of energy collection.

The control of heat loss will be addressed by managing convection through the use of:

- double glazing;
- honeycomb transparent insulation materials;
- single transparent films; and
- by applying heavy molecules to create an inert inner atmosphere.

Work in these areas will lead to so-called advanced flat plate collectors. Heat loss control will also be addressed by the introduction of concentrators, with or without tracking. The maximisation of energy collection will encourage the use of high performance optics, such as CPC in single or double stage concentrating steps. Evacuated tubular collectors with concentrators could be useful in tackling both these issues.

For process heat collectors, research into materials is crucial. Long-term resistance of components at ever higher temperatures must be improved and better materials are needed to produce the concentrating optics. These developments will also require a corresponding evolution in manufacturing techniques, systems testing and certification and installation.

8.1.2.3 Non-technical challenges for solar process heat collectors

For most industrial processes, continuity of operation must be guaranteed. Managers of industrial facilities are, therefore, sceptical about any intervention that could potentially cause interruptions to the heat supply system. The fact that there are only a few working solar thermal process heat systems means that trust in these systems has not been built up, potential users are not attracted and costs are increased for individual projects.

At the same time, industrial heat users are often able to purchase oil or gas at much better rates than private households, increasing the barriers to solar fuel savers.

In order to reduce these non-technical barriers to the wider deployment of solar process heat, it is important to:

- establish strong and focused financial incentives, leading to a significant number of demonstration projects, possibly with the goal of creating critical mass in a specific industrial and/or geographical sector;
- adjust existing quality norms and certification procedures for low temperature collectors, making them applicable to process heat collectors; and
- promote solar thermal energy service companies (ST-ESCOs), offering their services to the industrial sector.

8.1.3 R&D agenda

The fundamental challenge here is the development of a new generation of process heat collectors, raising the temperature, efficiency and performance of current low temperature collectors.

The main **basic research** topics arise in the field of materials research.

- Functional surfaces (such as anti-reflective or low-e coatings, self-cleaning surfaces and anti-corrosive coatings)
- Highly reflective, precise and weather resistant lightweight reflectors
- Improved selective absorbers (for example, long-term stability in aggressive climates, such as salt-water droplets from the sea)
- Cheaper glass with high solar transmittance and exchangeable optical properties
- Heat transfer fluids with higher temperature stability (above 160 °C)
- Temperature-stable and inexpensive thermal insulation (for example, vacuum insulation)
- New design concentrators, favouring roof mounting and low maintenance needs
- New heat transfer media, withstanding freezing and high operating temperatures
- New concepts for system integration and overheating protection

Depending on the price evolution of current raw materials, such as copper, aluminium and oil-based plastics, substitution materials may need to be developed. New concepts like PV-thermal collectors will require specific basic developments, which are not currently available.

The main **applied research** topics are:

- New manufacturing techniques for the large-scale production of medium temperature collectors and components.
- Stagnation-proof collectors and ways to prevent or mitigate the difficulties associated with stagnation. This is particularly relevant for industrial processes that do not run continuously.
- Reliable methods to remove air from the collector circuit, in order to achieve an even flow distribution and to slow down the aging of the heat transfer fluid.
- New testing techniques geared towards accelerated aging tests of solar system collectors and components, covering specificities arising from the use of collectors in facades and maritime ambience.
- Large systems control and management, reducing maintenance costs without lowering performance.
- Simple concepts for quasi–stationary concentrators (tilt adjusted).
- Integration with conventional heat sources or into conventional systems.
- Integration into building surfaces (for example, in combination with shading devices).
- Component durability without lowering performance (light and cheap reflecting surfaces and conventional selective absorbers).
- Precise, robust and cost-effective tracking devices (adjusted according to the required degree of accuracy).
- Solar air process heat collectors.

The main topics for **development** are:

- Develop cheap and reliable collectors based on new materials, which are easy to integrate into various roofs and facades.
- Develop practical ways to integrate conventional metal collectors onto metal facades and roofs.
- Develop collectors that can be connected with a heat pump (i.e. condensation inside the collector must not be a problem)
- Improve heat transfer in the collector and heat exchanger
- Develop cheap, energy-efficient pumps
- Develop connectors that facilitate the quick and easy installation of collectors.
- Develop evacuated tube collectors with a better price/performance ratio (soda-lime glass and anti-reflective coatings).
- Develop low concentration stationary or quasi-stationary collectors for higher temperature applications in buildings, which can be combined with evacuated tubular collectors.
- Develop PV-thermal hybrid collectors that save installation costs and increase total conversion efficiency, compared with side-by-side systems.
- Air collectors with improved heat transfer.
- Develop cheap sensors and electronics for fault detection and identification.

8.1.4 Timetable

Timetable specifics for **low temperature collectors**:

	Short term 2008 – 2012	**Medium term** 2012 – 2020	**Long term** 2020 – 2030 and beyond
Industry manufacturing aspects	• Absorber production technologies • Combining collectors and building components	• Automatic production of collectors as building components	• Full integration of new solutions in building codes and practices
Applied/advanced technology aspects	• Improved sensor technology • The use of colour in solar collectors • Test procedures for accelerated life time tests • Air collectors providing heat-ing and cooling	• Window-like technology for collectors • PV-T collector	• Hybrid PV-T col-lector with stor-age for facade integration
Basic research fundamentals	• Heat transfer fluids • Vacuum insulation • Functional coat-ings • New materials	• Polymer absorbers, boxes, and covers • Combined collector-storage systems • Switchable coat-ings	• "Invisible" col-lector is a practi-cal reality

Time table specifics for **process heat (medium-temperature) collectors**:

	Short term 2008 – 2012	**Medium term** 2012 – 2020	**Long term** 2020 – 2030 and beyond
Industry manufacturing aspects	Development goal: • Process heat collector: 600 €/kW_{th} • Manufacture first pilot plants based on the prototype collectors developed in recent years • Installation of subsidised pilot projects on the basis of existing technologies • Discuss integration of process heat collectors in existing standards	Development goal: • Process heat collector: 400 €/kW_{th} • First industrial-scale manufacturing of process heat collectors • Gradual reduction in subsidies for demonstration projects • Implementation of standards in a European and national framework	Development goal: • Process heat collector: 300 €/W_{th} • Fully industrial-scale manufacturing of process heat collectors • Reach baseline of subsidies for a large number of industrial process heat projects in all European countries • Implementation of standards that cover all available collector technologies
Applied/advanced technology aspects	• Development of performance test procedures for process heat collectors • Improved and cost effective tracking systems • Integration of process heat collectors into industrial buildings • Standardised system designs • Investigation into process integration	• Performance test procedures implemented • Second generation of process heat collectors at significantly lower cost and increased performance, due to the use of new materials	• Full integration of process heat collectors into industrial building structures • Standardised solar heat integration

	Short term 2008 – 2012	**Medium term** 2012 – 2020	**Long term** 2020 – 2030 and beyond
Basic research fundamentals	• New optical designs • New materials for: - structures - reflectors - receivers - heat transfer media • Life-cycle Cost Assessment LCA • Reliability and durability of materials	• Higher performance materials • Introduction of new materials • New concept testing	

8.2 Thermal storage

Heat storage increases the use that can be made of the solar resource by allowing heat to be 'consumed' when there is demand for it, rather that at the time when it is produced. Storing solar heat for one or two weeks, is a common practice, with acceptable costs and heat losses. Different solutions for heat storage on a timescale of seasons (several weeks or months) have allowed solar heat accumulated over the summer to be used during the winter months. However, these technologies are still in their infancy. Only when seasonal heat storage is widely available at low costs will it be possible to achieve the ESTTP's vision of 100% solar space heating as standard in new buildings.

Some of the key parameters to be considered for thermal storage systems are: cost, capacity, charge and discharge power, space taken up by the heat store, time between charging and discharging, transportability, safety, and integratability into building systems.

Short-term buffer storage systems show short reaction times, and must deliver high power with small capacities. "Medium term" stores define stores from one day upwards. Low storage capacities are measured in the kWh scale, while large ones are in MWh.

The size of the store depends on the specific heat capacity of the heat storing medium (usually water), the heat capacity of which is relatively low: large volumes are needed to store relatively small amounts of heat. This is a problem because space inside (or below) buildings is expensive. For example, in order for solar energy to cover the full space heating and hot tap water needs of a well-insulated house in Central Europe, a typical water heat storage of about 30m^3 at 85 °C would be required, equivalent to 10% of a typical house's usable space! The ratio of store size to building size is better in larger buildings with many residential units.

The large size of season-scale stores makes it difficult to use solar heat in winter. It is also difficult to integrate such systems into existing buildings. Therefore, developing new, compact season-scale heat storage technologies is crucial for the commercialization of solar thermal systems capable of covering 100% of space heating and domestic hot water demand.

Another important parameter is the required storage temperature. Low temperature stores are used in buildings to stop room temperatures falling below 20-24 degrees. The termperature of the storage medium is less than 100 °C. Medium temperature stores store heat for industrial applications at temperatures exceeding 100°C, where non-pressurised liquid water cannot be used as a storage medium. The upper temperature limit corresponds to the temperature limit defined for low or intermediate concentrating solar collectors.

Heat can be stored at low temperatures for periods up to six months. The size and capacity of the storage technology is not only determined by the storage period, but also by the building's demand for heat. For example, there is a significant difference in heating demand between an office building in the Mediterranean area and a one-family house in Denmark.

The theme of "thermal storage" also includes systems that store cold. It can be wise to include cold storage in thermally-driven refrigeration systems (see later).

8.2.1 Technology status

Figure 24: Water filled heat storages are currently the most common sensible heat storage systems. (Source: Vaillant, Germany)

Four main types of thermal energy storage technologies can be distinguished: sensible, latent, sorption and thermochemical heat storage[2]. **Sensible heat** storage systems use the heat capacity of a material. When heat is stored, the temperature of the material increases. The vast majority of systems on the market is of this type and use water for heat storage. Water heat stores cover a very broad range of capacities, from several hundred litres to tens of thousands of cubic metres. Medium temperature heat is stored in a single-phase storage material. In single-phase materials, the state of charge corresponds to the temperature of the material concerned. Examples of materials are concrete, molten salt, or pressurised liquid water. Storage systems using molten salt at temperatures between 300°C-400°C were demonstrated in solar thermal systems in 2008.

2 **Thermal energy storage for solar and low energy buildings.** State of the art by the IEA Solar Heating and Cooling Task 32. June 2005, editor Jean-Christophe Hadorn, ISBN: 84-8409-877-X.

Figure 25: An experimental latent heat storage with macro encapsulated PCM (paraffin). (Source: Ciril Arkar, University of Ljubljana, Slovenia)

In **latent heat storage** systems, thermal energy is stored during the phase- change, either melting or evaporation, of a material. Depending on the temperature range, this type of storage is more compact than heat storage in water. Most of the currently used latent heat storage technologies for low temperatures are for storing heat in building structures to improve thermal performance, or in cold storage systems. For medium temperature storage, materials used for storage are nitrate salts. Pilot storage units in the 100 kW range are currently operated using solar steam.

In **sorption heat storage** systems, heat is stored in materials using water vapour uptaken by a sorption material. The material can be either a solid (adsorption) or a liquid (absorption). These technologies are still largely in the development phase, but some are on the market. In principle, sorption heat storage densities can be more than four times higher than sensible heat storage in water.

In **thermochemical heat storage** systems, the heat is stored in an endothermic chemical reaction. Some chemicals store heat 20 times more densely than water, but more usually, the storage densities are 8-10 times higher. Few thermochemical storage systems have been demonstrated. The materials currently under investigation are all salts that can exist in anhydrous and hydrated form. Thermochemical systems can compactly store low and medium temperature heat.

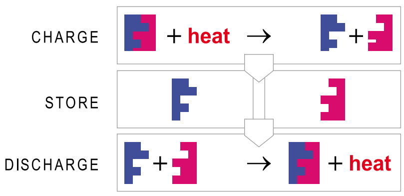


Figure 26: The principle of thermochemical heat storage: heat is used to separate a chemical compound into its component parts. The components can then be stored for long periods with practically no heat loss. When the components are reunited, a chemical reaction occurs and heat is produced. (Source: ECN, The Netherlands)

8.2.2 Potential and challenges for technological development

In order to achieve a larger solar fraction in housing stock, a new generation of thermal energy stores are needed. These stores must be compact, cost effective, safe, clean and easy to handle. To meet these requirements, new materials and technologies must be developed.

At present, the research groups working on thermal energy storage are spread around Europe, small, and insufficiently aware of each other's work. For decades, the main potential beneficiaries of thermal storage technology, which include the cogeneration and district heating sectors, have not funded the basic research needed to advance this technology. Nor have public bodies.

This might soon change. The creation of the European Solar Thermal Technology Platform, which is defining thermal storage as an R&D priority, aims to secure public and private spending on this research.

Innovation in compact thermal energy storage would be boosted significantly if a strategy were defined and executed between research centers and industry for this technology's short-, medium-, and long-term R&D.

8.2.3 Research agenda

A network of experts and companies interested in thermal energy storage should be built up. Sharing information, expertise and facilities effectively is a precondition for rapid progress in research, development and innovation. Public R&D funds should be earmarked for thermal storage at national and European level.

Basic research

Basic research in new materials to store much thermal energy in little space is essential, with thermochemical systems the front-running technology for the most compact systems. The materials in existing systems, based on PCMs and sorption should be improved or replaced with better materials.

The most important research topics are:

Material development

- Improvement of compact storage materials, such as zeolites, Metal Organic Framework (MOF), silica gels, hydration reaction thermochemical materials and other thermochemical materials. The development should be aimed at improving thermo-physical properties, including storage capacity, heat transfer, structural integrity and hydrodynamic behaviour.

Figure 27: Sample of magnesium sulphate powder - one of the thermochemical materials under investigation.
(Source: ECN, The Netherlands)

- Better understanding of the relation between structure, composition and thermal storage characteristics of these materials;
- Improved techniques for the synthesis and production of compact storage materials;
- Characterisation and standard tests for materials;
- Numerical models for molecular and crystalline interactions;
- Multi-scale numerical modeling: coupling of models on a micro and meso/macro-scale.
- Materials with high ability to insulate, including vacuum insulation and aerogels;
- Improved phase change materials (PCM) to achieve higher latent heat values at the appropriate temperature levels and gain a better understanding of how to master sub-cooling and the phase separation. Improve the long-term stability of PCMs.
- Understand the effects of combining materials from different classes, or combining a thermal storage material with a carrier material. Such as, silica gel and zeolite combinations; salt hydrate in zeolites; silica gels or zeolites in metal foams; and the use of carbon lattices.
- Combinations of active materials with a liquid carrier: suspensions of micro-encapsulated or micro-coated phase change materials, controlled crystallisation, emulsions of active materials, ionic liquids and the development of additives.
- Combined PCMs (organic and inorganic) in order to eliminate certain undesirable characteristics of individual PCMs;
- Materials and techniques for encapsulation and coating of phase change materials and materials that absorb heat by changing their chemistry;
- Suspension and emulsion techniques for compact thermal energy storage materials.
- Numerical models in order to understand the encapsulation process, material choices and the emulsion techniques.
- Laboratory tests and simulations to improve the interaction between multiphase flow and solid walls, thus increasing the heat transfer rate;

Chemical technology

- Thermochemical reactor technology for heat production and storage, using heat from distributed systems or solar collectors
- Two-phase reactors with optimised heat and mass transfer
- Micro-reactor systems for heat storage in distributed systems or in novel solar thermochemical collectors: heat and mass transfer on the micro-scale
- Reaction catalysis: understanding and developing the effect of catalysts on thermochemical processes
- Membrane technology: development of membranes for the selective transfer of reactants

Applied research

- PCM macro-encapsulation techniques that take into account material compatibility, safety and durability, with the aim of integrating PCMs into building construction and components
- Transport of powder, suspensions and emulsions for both PCM and thermochemical materials within systems and components
- Fast and secure connection of pipes and wires
- Low-cost sensors and communications technology for heat flow, fluid flow, temperature, pressure and composition
- Flexible volume tank systems; flexible walls or flexible diaphragms
- Further development of a range of reactors for thermochemical heat storage and for sorption thermal storage systems. These include hydrate powder, membrane and suspension reactors
- Study and optimisation of combined heat and mass transport inside a reactor
- Sorption material production technology development, with special attention to the combined production of sorption material and heat transfer surfaces
- Emulsion techniques for paraffin
- Measurement technologies to identify charging status of latent heat storage systems
- Optimisation of hydraulics in advanced water stores, reduction of mixing and increased stratification
- Coatings for tank and pipe surfaces
- Technologies to mix phase change materials with or into building materials
- Optimised or intelligent hydraulics and/or air flow schemes and control systems for the use of thermal storage in heating systems

Demonstration

It is necessary to demonstrate both the functioning of newly developed materials or methods, and to prove new concepts on the laboratory scale.

This should be followed by demonstrating the technology in a complete system, to ascertain the extent to which they improve on state-of-the art technology (i.e. what solar fraction they achieve). Several technology lines should be followed in parallel, including advanced water, PCM, sorption and thermochemical. The development of other components and auxiliary equipment should proceed in parallel. The durability of near commercial solutions, including their technical components, must also be demonstrated, in order to estimate their long-term performance. It is also important to demonstrate systems that include heat storage for short and long periods.

In medium temperature heat storage, the following should be demonstrated:

- employing thermal storage to reduce the start-up time;
- using storage to prevent system overheating;
- dynamic solutions for reaction time and peak-power of heat storage; and
- long-term performance of storage units.

8.2.4 Timetable

	Short term 2008 – 2012	Medium term 2012 – 2020	Long term 2020 – 2030 and beyond
Industry manufacturing aspects	• Advanced water heat storages • PCMs • Medium temperature storage cost • optimisation of design and norms • definition of standards	• Improved sorption systems • First systems with advanced heat storage materials	• Compact heat storage system technology • Commercial applications of low and medium temperature storage technologies

Applied/advanced technology aspects	• Improved production technologies for sorption materials and PCMs • Novel storage geometries and auxiliary materials • Control interfaces • First storage systems demonstrated to replace fossil fuelled facilities • Storage systems to reduce start-up time and compensate for cloud transients	• Production technologies for advanced materials and reactors • New medium temperature storage materials and concepts to be demonstrated	• Micro reactor devices • Synthetic materials from materials engineering. • New thermochemical systems • Medium temperature storage technology to enable solar only operation of solar thermal power
Basic research fundamentals	• Advanced materials for compact thermal storage • Reactor technologies • Development of theoretical and numerical methods • Reactor heat and mass transfer	• Micro reactor technologies • Numerical methods for materials engineering • Reaction catalysis, membrane technology • Second generation of medium temperature storage materials	

8.3 Solar thermally driven cooling and refrigeration

Most cooling and refrigeration systems worldwide are powered by electricity. Thermally driven cooling technologies 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 largely in combination with waste heat, district heat or co-generation units. One of the main advantages of such sytems is that thermally driven cooling cycles can be run with solar thermal energy, thus producing solar air-conditioning and refrigeration. Over the last two decades, most installations have been publicly funded, in the framework of research demonstration programmes. Only very recently, the start of market development has been observed in the residential sector in Mediterranean countries, particularly in Spain. There is substantial potential to support this development with further R&D work.

Industrial refrigeration

There is a large and slowly growing market for industrial refrigeration, especially for food or medicines. Refrigeration units will deliver temperatures in the range -30°C to 20°C. The output of most units is in the range of 100 kW to several MWs.

Conventional systems are operated by large, electrically driven, vapour compression refrigeration machines, which supply cold air to a distribution network. The performance of a refrigeration cycle is usually described by the coefficient of performance (COP), defined as the benefit of the cycle (amount of heat removed or cooling capacity), divided by the total energy (or power) input required to operate the cycle. The COP of electrically driven cooling machines ranges from 3 to 6, and is largely a function of the required output temperature. Usually, large cooling towers are employed to dissipate condenser heat.

Several industrial installations use waste process heat to operate thermally-driven cooling equipment, which is competitive with vapour compression technology in areas with an unstable electricity supply. Thermally-driven cooling systems applied for industrial refrigeration always use closed thermodynamic cycles, which produce cold air, which is transferred by a liquid (or solid/liquid, such as ice slurries) heat-transfer medium. At present, solar thermally-driven industrial refrigeration includes systems employing roof- or ground-mounted low- and medium-temperature solar collectors. These systems can be coupled with hot or cold stores, depending on the application. Only a small number of these applications have been studied and a few new systems are in operation in the southern Mediterranean.

Currently, solar thermally-driven systems find it hard to compete with conventional, electrically- driven refrigeration equipment. The high capital cost of solar refrigeration is particular factor preventing wider market uptake. On the other hand, the rising price of electricity and the number of successful solar industrial refrigeration demonstration projects have made such systems more attractive. In this field, there still is a great potential to develop economies of scale in manufacturing, offering thus excellent medium-term prospects.

Air-conditioning of buildings

The demand for cooling in buildings is rising across the world and notably in southern Europe, in both the residential and tertiary sectors. This has created a massive increase in peak electricity demand, putting heavy demands on power supply infrastructure and generation capacity, increasing the risk of blackouts and of damaging the environment. Alternatives to electrical cooling need to be developed rapidly. While demand-side management is crucial, on the supply side solar thermal is the best medium-term solution.

Around 250 solar air-conditioning systems were installed in Europe by 2007, with an exponential increase of activity in the last two years. Solar collectors for the air-conditioning of buildings are generally also used for other applications, such as space heating and domestic hot water production. This increases energy savings and thus the productivity of the investment. The systems in operation range from small units for single-family houses to large units for the air-conditioning of factory buildings.

Conventional air-conditioning is based on vapour compression cycles that consume significant amounts of electricity to drive the compressor. In the building sector, the market is dominated by small single-split systems (for a single room) or multi-split systems for a flat or a floor level. Typical COPs for small split systems are about 2.5 to 3. In larger commercial buildings, there often are cooling networks operated by large centralised water chillers. These systems can achieve much higher COP-values of up to 5-6, in particular when they use a wet cooling tower to reject the waste heat.

Although the basic principles remain the same, there are three main differences in the technologies used for air-conditioning in buildings and industrial refrigeration:

1. Air-conditioning of buildings in summer can include both cooling and, depending on the outdoor humidity and internal latent loads, dehumidification. So, both thermodynamic machines and so-called open cycles (also called desiccant cooling systems) can be applied. In open cycles, air passing through a thermally-driven air handling unit is brought to the correct temperature and humidity. The heat can come from solar collectors.

2. Depending on the indoor systems, the temperature of output air should usually range from 6°C to 16°C. Temperatures below 6°C are not necessary unless ice storage is required. Output termperatures in this range can be produced by solar thermal systems.

3. Systems for air-conditioning come in many sizes, from small water chillers, with a capacity of few kW for single-family houses, to centralised systems for air-conditioning large buildings, which can be in the range of several MW capacity. Small thermally-driven water chillers came on the market only very recently

Solar assisted air-conditioning of buildings currently requires low- and medium-temperature solar collectors, which are usually roof mounted. For large buildings, ground mounted collector systems are also used. There are two major types of cooling cycles:

- Open cooling cycles, in direct contact with environmental air. They use a sorptive component, able to dehumidify air. This increases the potential for using evaporative cooling. Heat is required to remove the water vapour bond in the sorption matrix.
- Closed cycle machines, employing a refrigerant that undergoes a closed thermodynamic process. It is thereby able to take up heat at a low temperature level (the useful cooling effect) that is then released at a medium temperature level (heat usually rejected into air). The process is driven by the difference in temperature between the input heat from the collectors or heat store and the temperature of the heat sink.

8.3.1 Technology status

Open cooling cycles (or desiccant cooling systems) as discussed above, are mainly of interest for the air-conditioning of buildings. They can use solid or liquid sorption. The central component of any open solar-assisted cooling system is the dehumidification unit. In most systems using solid sorption, this dehumidification unit is a desiccant wheel, which is available from several suppliers for different air volume flows. Various sorption materials can be employed, such as silica gel or lithium chloride. All other system components are to be found in standard air-conditioning applications with an air handling unit and include the heat recovery units, heat exchangers and humidifiers.

The heat required for the regeneration of the sorption wheel can be provided at low temperatures (in the range of 45-90°C), which suits many solar collectors on the market. Other types of desiccant dehumidifiers using solid sorption exist. These have some thermodynamic advantages and can lead to higher efficiency, but place higher demands on the material and the equipment. There is potential for further R&D work here.

Liquid sorption techniques have successfully been demonstrated. The input air is dehumidified when it comes into contact with a salt solution, such as water/lithium chloride. The diluted solution is re-concentrated using low temperature heat that can be provided by solar collectors. The advantage of liquid sorption is the capacity of the concentrated and diluted salt solution to store energy, without heat loss. This enables high density energy storage. The temperature required for regeneration is comparable to that required for solid sorption, and is thus perfectly compatible with solar collectors.

Closed heat driven cooling cycles have been known for many years. They are usually used for large capacities, from 100 kW upwards. The physical principle used in most systems is based on the sorption phenomena. Two technologies are established to produce thermally driven low and medium temperature refrigeration: adsorption and absorption.

Absorption technologies cover the overwhelming majority of the global thermally driven cooling market. The main advantage of absorption cycles is their higher COP values, which range from 0.6–0.8, for single stage machines, and 0.9–1.3 for double stage technology. Typical heat supply temperatures are 80–95°C and 130–160°C respectively. The absorption pair in use is either lithium bromide and water or ammonia and water. For lithium bromide and water cycles, the evaporator temperature is limited to 4°C and the condenser temperature is below 35°C. The condenser temperature means that a costly and high water consuming wet cooling tower is often required. Ammonia and water cycles allow for designs that can reach evaporator temperatures of below 0°C, and heat rejection temperatures of up to 50°C. Therefore, they can be used for deep freezing applications, using dry air-cooled condensers for heat dissipation.

Adsorption refrigeration cycles using, for instance, silica gel and water as the adsorption pair, can be driven by low temperature heat sources down to 55°C, producing temperatures down to 5°C. This kind of system achieves COP values of 0.6-0.7. Today, the financial viability of adsorption systems is limited, due to the far higher production costs compared to absorption systems.

A number of thermally-driven cooling systems have been built employing closed thermally-driven cooling cycles, using solar thermal energy as the main energy source. These systems often cater for large cooling capacities up to several hundred kW.

In the last 5-8 years, a number of systems have been developed in the small capacity range, below 100 kW and in particular below 20 kW down to 4.5 kW. These small systems are single-effect machines of different types, used mainly for residential buildings and small commercial applications.

While open cooling cycles are generally applied for air-conditioning in buildings, closed heat-driven cooling cycles can be used for both air-conditioning and industrial refrigeration.

Other cycles - Other options for the conversion of solar energy into useful cooling besides sorption-based cycles also exist. In an **ejector cycle**, heat is transformed into kinetic energy of a vapour jet, which enables the refrigerant to evaporate. In a **solar mechanical refrigeration cycle**, a conventional vapour compression system is driven by mechanical power that is produced with a solar driven heat power (for example, Rankine) cycle, in which a fluid is vaporised at an elevated pressure by heat exchange with a fluid heated by solar collectors. Last but not least, electricity generated in a **photovoltaic array** can be used to operate ordinary vapour compression machines.

8.3.2 Challenges and potential for technological development

- **Increased cost-performance**: When compared to mechanical (i.e. electrical) vapour compression, heat driven cooling is still new and relatively unexplored technology. There is significant potential for lowering costs and/or increasing performance through technological improvements in basic materials, to component design and systems technology.
- **Lack of practical experience and specific know-how**: A major barrier to the widespread implementation of solar air-conditioning and refrigeration systems is the lack of awareness of and experience in these technologies. Too few people are knowledgeable both of solar thermal and air conditioning in buildings. The deficit in solar thermal knowledge is particularly marked among specialists in industrial refrigeration.
- **High investment cost**: Solar driven air-conditioning and refrigeration systems have a high capital cost because of the many components involved in the system: the cooling equipment, the solar collectors and the heat storage appliances. At present, these systems are not competitive with conventional electrically-driven cooling systems. This is especially the case of commercial applications, where a short return on investment is expected.
- **Lack of technology**: Most of the thermally-driven cooling components on the market now have not been designed to operate with solar energy. The designs must be adapted to cope with varying input temperatures and input powers.
  Efficient heat dissipation systems, which are easy to maintain and operate at low temperatures, are not yet available. New components need to be developed in both these areas.

- **Building integration**: At present, systems are added to a building after it has been built. In future, systems will increasingly be incorporated in new buildings as they are being built. Solar collector and heat sinks and heat stores could be integrated into buildings (the latter, for example, through phase change material in the building structure).
- **Use of solar cooling in industrial processes hindered by over-designed systems:** The cold supply from most equipment in industrial processes is provided at temperatures far below the levels that are actually required by the process. As a consequence, the potential for integration of solar driven refrigeration systems is significantly reduced, and in many cases excluded.
- **Lack of design guidelines and design tools**: There are only a few people and research institutes with experience in solar cooling for buildings; and even fewer with experience in solar refrigeration for industrial purposes. There is also a lack of design guidelines and tools specifically developed for solar cooling systems for particular applications. Stagnation-proof collector designs need to be developed. With these tools, costs could be brought down. These elements strongly contribute to the currently high cost of solar cooling.
- **Awareness**: particularly a problem for solar refrigeration.

8.3.3 R&D needed to achieve the goals

This section only covers research activities that specifically relate to thermally driven cooling. Research activities related to the components of solar thermal systems in general, such as solar collectors and thermal storage, are only mentioned if they need specific attention in relation to thermally driven cooling.

Basic research with the long-term aim of optimising thermally-driven cooling cycles is required. Basic research is needed to:

- achieve a higher co-efficient of performance (COP-values)
- make machines more compact
- enable machines to operate at lower driving temperatures

Research on new sorption materials, new coatings of sorption materials on heat exchanger surfaces, new heat and mass transfer concepts and the design of new thermodynamic cycles will be needed. It will also be needed for cold stores, which could use phase change materials and thermo-chemical reactions.

Basic research topics include:

- The development of new, highly porous sorption materials, in particular using adsorption chemistry. Many materials have not yet been fully investigated for heat transformation applications. Ionic liquids may also be candidates for new liquid sorption working pairs.
- Sorptive material coatings on different metal substrates for optimised heat and mass transfer
- Micro-fluid systems for compact, highly efficient heat exchangers in the sorption and desorption regimes
- New sorption heat exchanger matrices, such as metal foams
- Nano-coated surfaces in heat exchangers for reduced friction losses during fluid flow
- New materials for cold storage at different temperature levels for high storage density
- New cycles (high temperature lift; double, triple stage and novel open sorption) with optimised internal heat recovery for high COP-values
- Performance analysis tools, such as exergy analysis, life cycle analysis and comparison methodologies to assess new concepts
- Advanced simulation tools for systems modelling at different scales, starting from the molecular scale (sorption phenomena) up to the system scale

Applied research

The main focus of applied research is to develop machines or apparatus based on new approaches. Applied research also includes the development of test methods for the standardisation of thermally driven cooling cycles.

Applied research topics include:

- Integration of the new heat exchanger concepts, developed in fundamental research, into a machine concept
- Advanced machines based on the new thermodynamic cycles, including hybrid sorption-compression systems for operation with heat and electricity alternatively
- Highly compact machines of a capacity to cool a single room; these machines could be adapted for use in road vehicles
- Adjustment of machines for solar operation, i.e. under variable temperature and power conditions (highly flexible cycles)
- Advanced ejector cycles using different working pairs adjusted to different applications
- Advanced open cycles using liquid sorption materials with a high storage density

- Cooled open solid sorptive cycles with a high dehumidification potential for warm and humid climates
- Advanced control concepts for components and overall systems, including self-learning control, fuzzy logic and adaptive control
- Assessment of new heat dissipation options, using the air or ground as a heat sink. Heat dissipation devices must be adjusted to the various sizes and temperature levels of thermally driven cooling cycles and need to focus on low:
  - water consumption;
  - health risks;
  - power consumption;
  - initial costs;
  - operation and maintenance costs.
- Advanced modelling and simulation tools for the thermodynamic analysis of systems and to support the planning and design of systems
- Ways to integrate solar driven refrigeration systems with industrial processes
- Optimisation of large solar refrigeration plants
- Advanced control systems for the solar refrigeration systems (solar collection, cold production and cold storage charge and discharge)

Demonstration and technology transfer

- Commissioning procedures and guidelines
- Hydraulic concepts, design guidelines and proven operational and maintenance concepts for overall systems;
- Identification of the most promising industrial applications for solar refrigeration systems;
- Hybrid systems that combine compression technology with heat driven machines supplied with solar thermal heat and cold and (heat) storage
- Installation and long-term monitoring of various systems in different configurations, sizes, climates and operating conditions
- A set of standards for components and overall systems
- Documented experience in the practical operation of installations
- Development of appropriate training materials for different levels of engineering education

8.3.4 Timetable

	Short term 2008 – 2012	**Medium term** 2012 – 2020	**Long term** 2020 – 2030 and beyond
Industry manufacturing and technology transfer aspects	• Production of small capacity systems (e.g. for residential application) on a small industrial scale • Initiation of large-scale, monitored demonstration programmes in different regions and sectors • Suitable commissioning procedures and guidelines • Installation and long-term monitoring of large capacity systems in a wide variety of configurations and site conditions. • Development of performance criteria • Cooperation with machinery producer and adaptation of machines for solar cooling • Identification of the most promising industrial applications for solar refrigeration systems in energy and economic terms	• Large-scale industrial production of small capacity systems • Proven systems concepts readily available for large-scale implementation • Transfer to professionals on a large scale. • Highly efficient and user-friendly tools for systems design • Adaptation of processes for low and medium temperature solar refrigeration	• Solar cooling is part of standard professional education at all levels (installers, engineers and planers)

	Short term 2008 – 2012	Medium term 2012 – 2020	Long term 2020 – 2030 and beyond
Applied/advanced technology aspects	• New open liquid sorption cycles with high storage density • Cooled open sorption cycles • Development of integrated solutions for the best use of solar refrigeration in the industrial process • Development of new hybrid systems (solar driven and conventional technology) for different applications • Development of hydraulic concepts, design guidelines and proven operational and maintenance concepts	• Hybrid sorption-compression cycle ready for practical application • New cycles available for different technologies (sorption, ejector, open, closed) • Design and optimisation of large-scale solar refrigeration plants	• Compact closed machines for application in small capacity range, including automotive • High density cold storage available for industrial application (e.g. based on PCM or thermo-chemical) • Advanced overall solar cooling (and heating) systems with high integration

	Short term 2008 – 2012	**Medium term** 2012 – 2020	**Long term** 2020 – 2030 and beyond
Basic research fundamentals	• Screening of new sorption materials • Nano-coatings for heat exchanger developed • First design models on different levels (molecular, micro-technology) • Development of advanced cold storage materials • Development of new cycles (high temperature lift, higher COP and novel open sorption) • Development of new heat driven concepts (e.g. thermo-mechanical processes such as Rankine-Rankine)	• Successful laboratory development of advanced sorption materials • Availability of micro-fluid heat exchangers for thermally driven cooling • New heat exchanger matrices, such as metal foam • New storage materials • Powerful models for integrated process modelling on different levels (multi-scale models) • Development of new cycles (double, triple stage, novel and open sorption)	• Long-term, stable and cost effective new sorption materials applicable on industrial scale

8.4 Multi-functional components

By 2030, the solar building will have become a common sight. They will be attractive, comfortable and environmentally friendly. Its supply system will collect, store, distribute and provide thermal and electrical energy. And it will be constructed mainly from multi-functional building elements.

the building = the energy system

Multi-functional components combine the functionality of today's standard components (static, shelter from weather and fire resistance), with an ability to meet the energy requirements of the building, by producing, storing, distributing or dissipating heat.

Examples of multi-functional building elements are:

- Water pipes that also fulfil a structural function
- Facade collectors that reduce heat loss from buildings, serving as energy sources, heat sinks and/or stores, and provide shading
- Roofing elements that provide shelter, act as windows and as solar thermal collectors or PV modules, and which may be integrated with an energy storage module
- Walls that support the building or divide it into room, while acting as heat stores and thermal insulation
- Disguised collectors: a special kind of facade or roof-integrated collector that imitates building materials and fits aesthetically with historic buildings
- Intelligent building components, such as windows with self adapting transmission, based on the intensity of solar irradiance
- Collectors that serve as a balcony floor, terrace, shading device, or semi-transparent facade element

8.4.1 Technology status

Some examples of multi-functional components involving solar thermal or PV that have already been introduced into the built environment include:

- shading systems made from PV and/or solar thermal collectors;
- facade-collectors;
- PV-roofs;
- thermal energy roof systems; and
- Solar thermal roof-ridge collectors

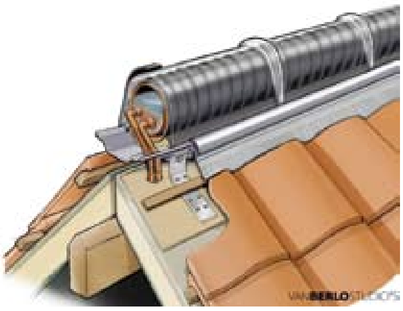


Figure 28: Example: A solar thermal roof-ridge collector is a "hidden" installation, which is already used in a few EU countries. It provides solar heat and also acts as a "standard" roof ridge. It has been developed primarily as an architectural solution to the integration of solar active roof elements, which will not impede subsequent roof alterations, such as the installation of a dormer window.
(Source: Inventum, The Netherlands)

Currently, fundamental and applied R&D activities are also underway related to the development of:

- transparent solar thermal window) collectors (see picture)
- facade elements consisting of vacuum insulation panels, PV-panels, heat pump and an heat-recovery system connected to localised ventilation (see picture)

Energy functionality is insufficiently integrated into the structural elements of buildings. Most multi-functional components are also added on after the construction of the building. It would be cheaper to add them during construction. Solar thermal elements could be integrated into prefabricated attic expansions, offering a standardised and therefore low cost way for people to build solar thermal into their lofts.

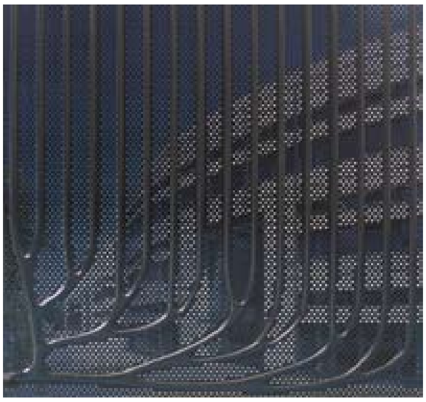


Figure 29: Transparent solar thermal collector (left). (Source: Fraunhofer ISE, Germany)
Figure 30: integral solar-active facade (right). (Source: www.smartfacade.nl)

8.4.2 Challenges and potential for technological development

Manufacturing and installing multi-functional building elements requires knowledge that can rarely be provided by a single person or installation company. The elements are unlikely to have the all advantages of all the building elements they replace without any disadvantages. Building designers sometimes fail to choose the best combination of multi-functional elements for their budget.

Because so few examples of their deployment exist, designers are reluctant incorporate multi-functional elements, fearing they will break down and won't resist bad weather.

The design of existing buildings is often not ideal for the integration of new types of energy systems. Perpetuating these design flaws in new buildings must be avoided.

There is a lack of advanced simulation tools that dynamically describe the exergy energy performance, room temperature and air replacement rate of a building design.

8.4.3 Research agenda

Basic research

The optimal use of the limited building shell area requires structural demands in building components to be combined with solar functions or heat storage and thin, highly efficient insulation layers.

Phase change materials are a promising option for short and medium term heat storages. Knowledge is needed of how to integrate this type of storage into the building when it is being constructed, for example in its walls.

Areas for development

Solar collectors that are part of the building shell need to be developed, as they combine several functions. They can be part of transparent facades and have daylight and shading functions, as well as their energy collecting function. Collectors integrated into opaque facades can protect against heat. In addition, they may act as a heat store and/or supply system on the internal wall.

Measures to optimise energy gains of facade-integrated collectors are also needed, such as partly tilted absorber components. Basic research in this field needs to focus on materials and be closely linked to applied research on components.
Advanced coatings need to be developed for windows with switchable variable transmission, or for collectors with controllable glazing transmission as well as absorptance. This is especially important for polymer-based collectors, in order to avoid stagnation problems.

Advances are needed in tools for commissioning buildings as a whole, and methods to ensure that predicted results are effectively obtained by the building. Standards for the hydraulic and electrical interconnectors of different building components are also required.

Applied research

The limited available space for solar systems on the roof requires developments in facade collectors and roof spanning systems to increase the usable surface area for the harvesting of renewable (thermal) energy.

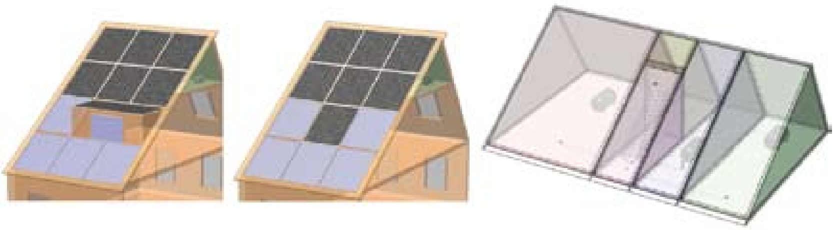


Figure 31: Modular roof elements for solar thermal and solar electrical panels (with or without a window) in combination with heat storage in the attic. (Source: ECN, The Netherlands)

The development of a HUB interface, such as facade-integrated systems for solar thermal collectors, would lead to further standardisation and make a modular design feasible. In turn, this may lead to the development of modular replacement elements, resulting in a complementary set of modular, multi-functional components and interfaces - the HUB toolkit. Typical elements of this toolkit could be:

- The distribution of heat and cold via pipes embedded in the construction, in which liquids or gases circulate, carrying the heat or cold
- Facade collectors used to collect a solar heat or radiate it in case of cold production, as well as for reducing heat loss
- Roofing elements that shelter and protect the building, or that let light into the building, while also generating or storing energy
- Collectors designed to resemble the building elements of old buildings, especially on the facade or roof
- Windows with self-adapting transmission, based on the intensity of solar radiation

Demonstration

New components and supply systems need to be tested in new and existing buildings. Prototypes of the HUB interface and modular elements need to be built as research into them goes on. This testing can be carried out at research laboratories and test dwellings at R&D institutes. At this stage, limits of the HUB-toolkit should also be determined.

When the HUB-toolkits are in the final stage of development before commercialization, complete HUB-toolkits should be made available through the construction and supply industries. Once it has won the approval of these users, the toolkit can be made available to housing corporations and the "do-it-yourself" market.

8.4.4 Timetable

	Short term 2008 – 2012	Medium term 2012 – 2020	Long term 2020 – 2030 and beyond
Industry manufacturing aspects	• Prototypes and possible structural components, such as HUB-interfaces for existing energy systems • Design demands for "missing links" (sub- systems) established • Definition of standardised hydraulic and electrical interfaces for the interconnection of different building components	• Proof of Manufacturing HUB interface and sub-systems • Major part of identified "missing links" available • The manufacturing and construction industry brings several variants to market, combining unique and common elements • Development of methods for the integral planning of buildings • Development of commissioning tools and methods to ensure that the predicted results are achieved by the building	• Large-scale implementation realised • Do-it-yourself renovation kits available for unplug-and-replace energy system components • Different, optical identical roof elements that provide shelter and fulfil different functions such as a window, solar water or air collector, PV module or energy storage module • Invisible collectors

	Short term 2008 – 2012	Medium term 2012 – 2020	Long term 2020 – 2030 and beyond
Applied/advanced technology aspects	• Set-up of common language/protocol for energy systems and modular system components • Set-up of common hydraulic and mechanical interfaces between collectors and facade systems • Construction of prototypes of first HUB-interfaces • facade collectors used as (solar) heat sources and heat sinks, as well as for heat loss reduction • Collectors that also act as flooring	• Set-up HUB toolkit for renovation • Intelligent building components, such as windows with self-adapting transmission, based on the intensity of the solar irradiance	• Monitoring and optimisation of HUB interfaces • Development of modular replacement elements

	Short term 2008 – 2012	Medium term 2012 – 2020	Long term 2020 – 2030 and beyond
Basic research fundamentals	• Establish renovation challenges between end-user demands (health, comfort, etc.), building process requirements and environmental impacts (energy, material, etc.) • Inventory of alternative functions of structural building components • Identification of "missing links" • Legal and/or architectural restraints, or boundary conditions	• Building Process Innovation: changing the value chain • Development of "missing links" • Development of testing methods and assessment procedures for various components of the supply system • Development of advanced coatings (e.g. for window collector glazing and absorbers within the collector), with variable absorptance and transmittance	• Systems study of new additions to HUB toolkit

8.5 Control systems

Solar thermal natural flow (thermosiphon) systems for domestic hot water production do not require a pump as the circulation arises naturally through the difference in density between hot and cold water. However, natural flow systems only cover domestic hot water demand. Forced circulation systems require a control system.

Typically, solar thermal control systems consist of a microprocessor controller, sensors for the detection of input parameters, for example, temperature and radiation, and actuators, such as pumps and valves. Together, these components control the collection, storage, distribution and emission of energy, thereby keeping the building's climate in line with the wishes of the building occupiers.

In some cases, solar thermal systems also require controllers to vent or send to a heat sink low temperature waste heat.

Solar thermal systems are frequently part of more complex heating systems, or possibly cooling and/or ventilation (HVAC) systems. In turn, HVAC systems are themselves part of a larger system (the building itself, with its natural or specifically designed ability to store heat). Control systems that control only one sub-system are often sub-optimal. Unfortunately, today's installations typically have separate controllers, which do not talk to each other, for hot water production, space heating and cooling and ventilation.

8.5.1 Technology status

Today, most control systems are based on micro-processors. Sensors are typically connected to the control system by wires. The control system can be based on simple or complex algorithms depending on a few or many parameters.

It would be best if one controller governed the whole HVAC system (and possibly lightning and other electrical applications and related sub-systems installed in a building). What stops this happening is inadequate standardisation of the interfaces and communication between the different HVAC sub-systems. No standard exists for communication between the sensors or the actuators and the control system, which leads to unnecessary cost, since the same measurement (for example, the temperature in a specific room) is often taken by two separate sensors, each of which provides a signal to a different controller.

8.5.2 Challenges and potential for technological development

The overall goal of future HVAC control systems should be to operate the whole system (e.g. a building) to minimise non-renewable energy consumption for a given setting of room temperature set by the users. Reaching the highest possible overall efficiency implies that one of the sub-systems may temporarily need to run at a sub-optimal level.

In order to overcome these problems, a detailed analysis of the energy fluxes within the entire system (for example, the building) is required. It is necessary to consider all the energy flows in a specific application and to develop one control centre for the entire energy system. The controller should remember the preferences of individual users and adjust the system according to these preferences while minimising energy consumption. Of course, the user should be able to override the system if it is not doing what (s) he wants.

In addition, the controller should notify the user when maintenance is required or when a malfunction is detected. Controllers should offer as standard the ability to compare the performance of the system they control with reference values for an optimised system operating under the same conditions (external temperature, solar radiation, internal temperature and hot water load).

Basic research

- Worldwide survey and benchmarking of available technical solutions
- Survey of available control equipment and control strategies
- Scenarios for user expectations of control systems in 2030
- Improvement of system and building simulation and design tools, in order to take into account all comfort parameters, such as temperature, humidity and light, as well as energy consumption.
- Methods to assess the environmental performance of the building as a whole over its lifetime are required. A common platform for the simulation data exchange between different stakeholders should be defined
- Development of advanced control equipment for the supply system that is easy to use and standardised
    - self-adapting and self-optimising strategies
    - control systems responsive to weather forecasts
    - user friendliness
    - integration of new automated methods, such as "fuzzy logic" controllers and control algorithms based on optimisation theory
    - the development of cheap and intelligent (for example, self-adapting) sensors, or the usage of "virtual sensors", estimating process conditions using mathematical models instead of, or in conjunction with physical sensors. Virtual sensors can be used if a physical sensor is too slow, too expensive or too complicated to be maintained
    - early detection of faults in the system
    - monitoring performance with advanced communication technologies like wireless
    - the integration of data acquisition and evaluation
- Development of communication platforms for data exchange between different components and the controller. These platforms can be based on wireless technologies or networks that already exist and are used for other purposes. This communication platform can also act as an interface for a "hardware-in-the-loop" simulation and testing of control strategies on the real system.
- Development of methods for the planning of the entire system/building, taking into account preferences for comfort, energy consumption, resources used and costs during the building's lifetime (life-cycle costs)
- Development of commissioning tools and methods in order to ensure that the forecast results are really obtained by the system
- Development of a standardised method for the assessment of the overall performance of the system/building and for checking if the requirements of the energy label are fulfilled

Applied research

Development of the supply system:

- Development of one centralised control system for the entire energy system. This means a system for the collection, storage, distribution and release of thermal energy
- The centralised control system should use all available sources for the collection of energy, such as solar radiation, ambient air, waste water and air, and the ground beneath and/or around the building.
- The centralised control system should manage the heat and cold stores in the system.
- With regard to the release of excess energy (for example, from a cooling machine), the centralised control system should sent it to the most appropriate heat sink (ambient air, perhaps, via solar collectors, waste water, the ground).

Demonstration

On-site testing of centralised controllers in new and old buildings, as well as kinds of energy systems such as solar process heat plants.

Capacity building

Training for technicians who will install the advanced centralised controllers. People must be trained in monitoring the system, to a deeper level than the installers.

8.5.3 Timetable

	Short term 2008 – 2012	Medium term 2012 – 2020	Long term 2020 – 2030 and beyond
Industry manufacturing aspects	• Survey and benchmarking of currently available technical solutions and experiences • Definition of standardised electrical interfaces for the interconnection of different sensors and actuators to the control system	• Development of methods for the integral planning of the building / system as a basis for the programming of the control system • Development of commissioning tools and methods to ensure that predicted results are really obtained by the building / system	• Wireless connection of mobile units to the control system as user interface (e.g. for displaying the system status and user-based interaction)
Applied/advanced technology aspects	• Further development of self-learning / self-adapting control strategies	• Development of advanced control equipment for the entire energy system	• Advanced building components, such as windows with controllable transmission
Basic research fundamentals	• Determination of user expectations for the controller / building in 2030	• Development of testing methods and assessment procedures for different components of the supply system, especially with regard to controller dependent behaviour	• Strategies for the wireless determination of the user operation parameters (such as temperature) and senses (for example feeling hot or cold)

8.6 Water treatment (desalination)

This chapter refers to **thermally driven, decentralised water treatment** systems, such as sea water desalination), which provide high quality drinking water to isolated customers, such as single households, small- to medium-sized communities and remote resorts. The needs of different target groups map to three categories of system sizes, each based around a different combination of technologies.

Small-scale solar driven desalination processes
(0.01 to 0.5 m^3/day)

This size is typically required for individual buildings. Typical technologies within this scope are:

- Classical solar stills without heat recovery
- Watercone® technology
- Multiple effect solar stills applying limited and very easy heat recovery
- Small-scale membrane distillation units
- UV disinfection using PV, photocatalytic disinfection

Medium-scale solar driven low temperature thermal desalination processes
(0.5 up to 100 m^3/day)

These processes are typically used for hotels, holiday resorts and small communities:

- Multi-effect Humidification Dehumidification process, MiniSal™ MidiSal™, MegaSal™ units
- Membrane distillation units
- Other new processes (solar MED, solar MSF)

Mid-scale hybrid electricity and water generation
(up to 1 MW_{el} and 500 m^3/day water)

- Combined Heat and Power (CHP) generators, solar assisted thermal share
- Use of waste heat from diesel or vegetable oil-based generators
- Multi Effect Solar Desalination

Large-scale combined thermal electricity and water generation
(from 500 m³/day and 0.2 MW_{el})

These installations can cover the needs of larger communities, and medium- to large-sized tourist resorts. The typical technologies used in them are solar thermal power plants using parabolic trough or Fresnel collectors, with steam generators for electricity production and waste heat used for desalination.

Renewable energy-driven water disinfection or grey water recycling

- Solar driven catalytic water disinfection
- PV driven ultraviolet radiation disinfection

Industrial water treatment by renewable energies

Recent research activities on solar powered membrane distillation (MD) systems focus on small and medium-scale seawater desalination units. MD, as an innovative and alternative desalination process, differs from conventional membrane technologies like reverse osmosis (RO), in that the membrane is permeable only to gas or vapour and impermeable to liquids. Thermal energy, such as solar heat or waste heat, can be used for phase changing, and therefore for the separation process. In the reverse osmosis process, pressure is used to force a liquid through the membrane, which retains salts and other dissolved matter. This makes the system energy intensive and, especially for small seawater desalination units, uneconomical.

The implementation of small and medium-scale solar powered membrane distillation units in industry is still unusual, although MD is a well-known technology and, in principle, suitable for purifying water, dewatering waste liquids and generating concentrates (food industry). The main barriers to this technology are the low permeate flow rate, MD membranes and the integration of solar heat systems into industrial MD applications. Future research work in the field of MD should focus on these areas.

8.6.1 Technology status

Solar stills are already widely used in some parts of the world (for example, Puerto Rico) to supply water to households of up to 10 people. The modular devices supply up to 8 litres of drinking water from an area of roughly 2 m². The potential for technical improvements is to be found in reducing the cost of materials and designs. Increased reliability and better performing absorber surfaces would slightly increase production per m².

Multiple Effect Humidification (MEH) desalination units indirectly use heat from highly efficient solar thermal collectors to induce evaporation and condensation inside a thermally isolated, steam-tight container. By solar thermally enhanced humidification of air inside the box, water and salt are separated, because salt and dissolved solids from the fluid are not carried away by steam. When the steam is recondensed in the condenser, most of the energy used for evaporation is regained. This reduces the energy input for desalination, which requires temperatures of between 70 and 85°C. Over the years, there has been considerable research carried out into MEH systems and they are now beginning to appear on the market.

The thermal efficiency related to the solar collector area is much higher than for solar stills. The specific water production rate is in the region of 20 to 30 litres per m² absorber area and day. At the same time, the specific investment is less than for the solar still, as the solution is available for sizes from 500 up to 50.000 litres per day.

Membrane distillation (MD)

Membrane distillation is a separation technique, which links a thermally-driven distillation process with a membrane separation process. The thermal energy is used for turning water into vapour. The membrane is only permeable to the vapour, and separating the pure distillate from the retained solution. MD offers important advantages for the construction of solar driven, stand-alone desalination systems or applications where waste heat is available.

Fraunhofer ISE is developing solar driven compact desalination systems, using MD for capacities between 100 and 500 l/day, and larger systems ranging up to 20 m³/day. All systems are solar energy-driven, but could also be operated with waste heat. The electricity for auxiliary equipment, such as pumps and valves, could be supplied by photovoltaic modules.

Five compact systems for fresh water capacities of about 100 l/day and two doubleloop systems (1x 1000 and 1x 1600 l/day) have been installed in different test sites.

8.6.2 Barriers to increased deployment

Higher investment costs: unfortunately, all renewable energy driven systems have high upfront costs and take a long time to pay for themselves. This is caused mainly by the cost of supplying heat (for example, solar thermal collectors and thermal storage), rather than by the cost of the desalination modules. Desalination systems must be designed to last a long time and require little maintenance.

This adds to the costs, making this technology prohibitively expensive for end users, unless subsidised.

Lack of suitable design guidelines and tools: worldwide, there are only few specialists in solar desalination installations. More people must be trained in the technology.

Awareness: Too few people are aware of the potential of renewable-energy-driven desalination technology. National or regional development plans for water systems often only consider centralised solutions. The economic and practical advantages of decentralised solutions, based on solar energy, need to be highlighted.

8.6.3 R&D needed to achieve the goals

Basic research

- R&D on new/innovative materials (low cost/high durability) for efficient thermally-driven heat and mass transfer (evaporation and condensation
- Polymer science (functional material foils and fabrics, heat conducting polymers) - Market research
- Multi-water quality generation, combination of desalination methods, such as, RO/MEH
- Multi-stage thermal desalination, salt production with high recovery rate of 30 to 50%
- Chemical-free raw water pre-treatment

Applied research

- Increase the efficiency of solar power generation for desalination purposes
- House- / building-integrated desalination system designs; desalination becomes part of house technology
- Systems that are easy to build and maintain for decentralised, small-scale applications, which do not need an external power supply (electricity or fuel)
- New solar collectors and storages adapted for the needs of solar desalination systems: mid temperature (90 -50°C, resistant against salty sea air)
- Combination of solar thermal desalination and power generation
- Multi-stage desalination, applying several processes consecutively, in order to increase recovery up to 75%
- Integration of desalination devices in buildings
- Systems designed for ease of use
- Awareness raising of solar thermal driven desalination as a cost efficient and reliable alternative
- Finding of the limits of the production range of possible systems
- Demonstrate consistent system performance after long periods of operation
- Development of low cost and robust designs to make it easier to deploy in environments where specialists will rarely, if ever, be able to repair or maintain it

Demonstration

- Building integration
- Ease of operation, confirmation of low energy demand
- Awareness raising of solar thermal driven desalination as a cost efficient and reliable alternative
- Clarification of the wide production range of possible systems
- Continuous operation and permanent water quality
- Development of low cost and robust concept for easy technology transfer

8.6.4 Timetable

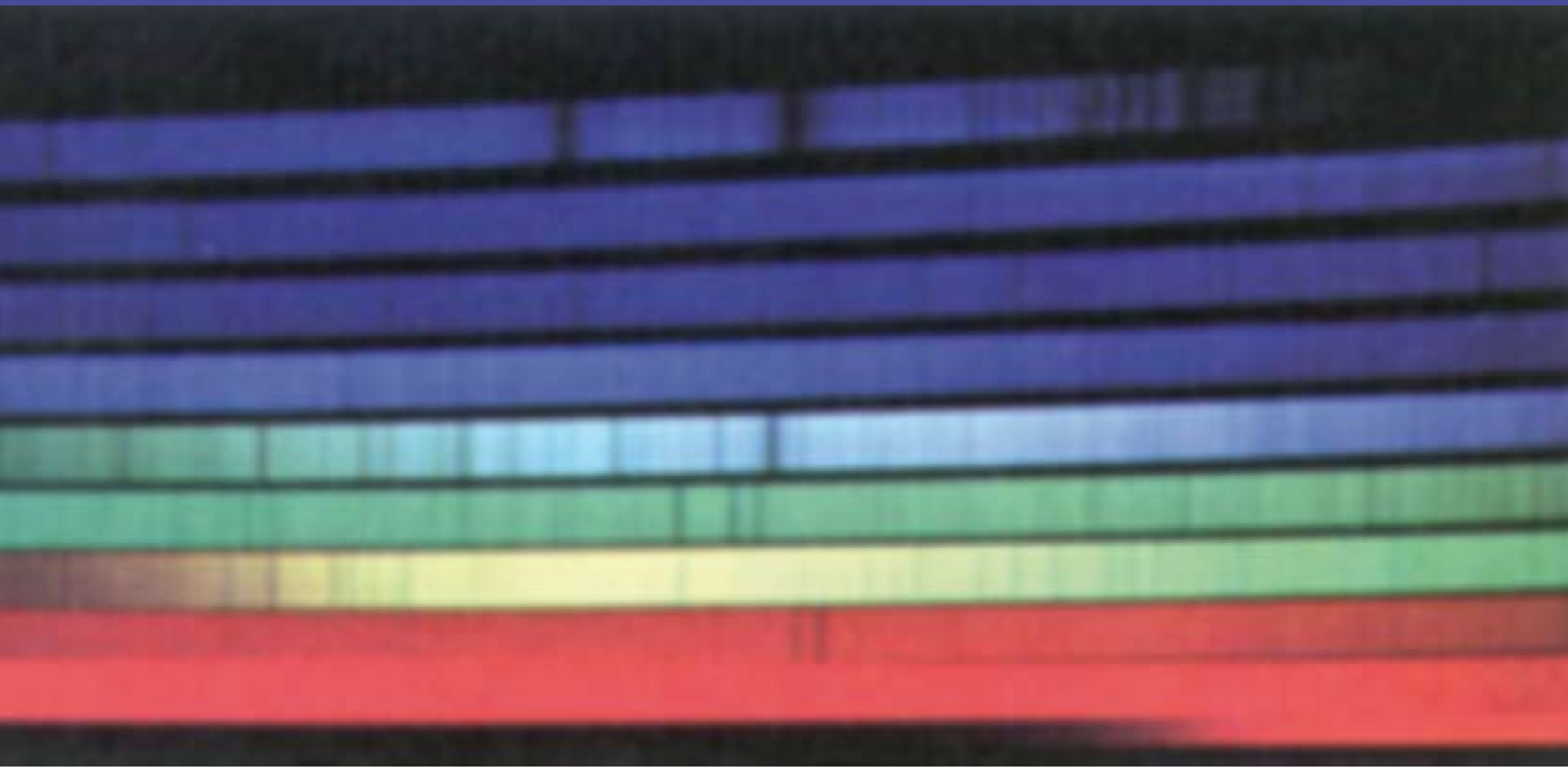
	Short term 2008 – 2012	**Medium term** 2012 – 2020	**Long term** 2020 – 2030 and beyond
Industry manufacturing aspects	• Quality control • Maintenance control and implementation • Cost reduction of system • Standardisation of testing criteria for water and energy demand • Easy and maintenance free water pre-treatment for thermal desalination without fouling and scaling • Envisaged: efficiency increase of thermal processes depending on the capacity • System design for small applications • Cost efficient, integrated transport casing designs	• Mass production • Further cost reduction at stable quality and durability • Lean production, easy design for assembly in countries of application	• Standardisation and implementation of systems • Permanent quality control by remote control • Maintenance control and implementation • Further cost reductions

	Short term 2008 – 2012	Medium term 2012 – 2020	Long term 2020 – 2030 and beyond
Applied/advanced technology aspects	• Minimisation of additional electrical energy demand • Optimisation of operation and maintenance • Easy and maintenance free water pre-treatment for thermal desalination without fouling and scaling • Envisaged: efficiency increase of thermal processes depending on the capacity • System design for small applications • Cost efficient, integrated transport casing designs	• Building integrated system designs - desalination becomes part of house technology • Easy to build and maintain systems for decentralised, small-scale applications without the need for external power supply (electricity, fuel) • New solar collectors and storages adapted to the needs of solar desalination systems: mid-temperature (90 -150°C, suitable for long-term resistance to an aggressive sea-side atmosphere • Combination of solar thermal desalination and power generation • Multi-stage desalination applying several processes consecutively, in order to increase recovery up to 65%	• Standardisation • Quality control • Maintenance control and implementation • Cost reduction

	Short term 2008 – 2012	Medium term 2012 – 2020	Long term 2020 – 2030 and beyond
Basic research fundamentals	• R&D on new/ innovative materials (low cost/ high requirement) for efficient thermally driven heat and mass transfer (evaporation and condensation) • Efficiency increase of solar power generation for desalination purposes • Polymer science (functional material foils and fabrics, heat conducting polymers) - market research • Multi-water quality generation, combination of desalination methods • Multi-stage desalination, salt production, high recovery 30 to 50% • Develop low cost and robust concept for easy technology transfer	• Standardisation • Quality control • Maintenance control and implementation • Cost reduction	• New materials and processes

Fraunhofer Lines Diagram. SPECTRUM OF VISIBLE LIGHT from the Sun shows a continuum of colors crossed by dark absorption lines

Source: http://de.wikipedia.org/wiki/Bild:FraunhoferLinesDiagram.jpg (created by NASA)



9 Research Infrastructure

9 Research Infrastructure

This chapter indicates a number of requirements for the development of research infrastructures, which are necessary to implement ESTTP's Strategic Research Agenda.

Following the definition proposed by the European Roadmap for Research Infrastructures, published in 2006 by the European Strategic Forum on Research Infrastructures, Research Infrastructures are "... facilities, resources or services of a unique nature that have been identified by pan-European research communities to conduct top-level activities ... Research Infrastructures may be single-sited, distributed, or virtual ..." Under this definition, Research Infrastructures include human resources, equipment, as well as repositories of knowledge, such as archives and databases. In general, such infrastructures are costly and are most efficiently set up at a pan-European level.

As a specialised pan-European research and industry platform, the ESTTP has identified a need for Research Infrastructures at European level in the following areas:

- Solar assisted cooling and air-conditioning
- Medium-temperature (process heat) collectors
- Heat storage

Compared with other energy technologies that require billions of Euros in R&D investment, solar thermal R&D is cheap. Furthermore, solar thermal is highly likely to produce applicable results within a relatively short time.

9.1 Solar assisted cooling and air-conditioning

Basic and applied research in the field of thermally driven cooling is currently dominated by Japan and, increasingly, China (the USA led the market in the 1980s). Europe lagged behind for some time, but due to advances in the efficiency of energy transformation chains, European R&D institutes and universities have been increasing their efforts on thermally-driven cooling technology, and specifically on its operation in combination with solar energy. Today, Europe is one of the global leaders in the implementation of solar thermal cooling technology.

In several EU countries, research infrastructure for basic and applied research in this field is fairly well established. There is definitely a need for a well-organised exchange on test standards for new machines and cycles. A joint effort for large-scale demonstration is needed to ensure successful market introduction. At the same time, the next phase of development will require focus on technology transfer, widespread demonstration projects and training.

A structured collaboration among European research institutes and industry will support rapid commercialisation of solar driven cooling technologies, strengthening the European dimension of this industrial sector. This collaboration should consist of:

- RD&D Network
- One "Joint European Laboratory"
- Regional Solar Cooling Development Centres for demonstration, technology transfer and training

Networking activities can lead to a powerful effective exchange between those involved in the sector's R&D, which will reinforce European leadership and guarantee the rapid achievement of optimal technology development. The required infrastructures for these networking activities are mainly virtual.

Concerning physical infrastructures a **Joint European Solar Heating and Cooling Laboratory**, must be built. In this Laboratory, the common efforts of institutes active in solar energy research, process engineers, and refrigeration experts will lead to the development of European products for the Mediterranean, Asian and other markets.

This centre should be situated in Southern Europe to take advantage of the higher cooling demand and solar resource. The laboratory will be a decentralised facility for the European researchers and industry (who are mainly based in northern countries), offering the opportunity to test components or systems under real life conditions (e.g. (1) medium temperature collectors, based on concentrating technologies, that need a high ratio of direct to global radiation. (2) thermally driven systems, which can be tested under hot and humid climate conditions). Such a research infrastructure should also be used for collaborative research work connected to the use of solar thermal technologies that are not directly connected to cold production, for example, desalination.

While the infrastructures for R&D and testing should ideally be set up at a European level in the Joint Laboratory discussed above, a small number of **Solar Cooling Development Centres** should be set up at national or regional level in high potential regions (all the Mediterranean basin and Southern Balkans). In the next phase of development, hundreds of systems will be installed in each of these regions. Visible and well managed demonstration projects for different applications will be important, and the monitoring of their performance and good access to this monitoring data will accelerate innovation. Well trained engineers and installers will do installations of high quality, achieving big energy savings for their customers and a helping to make the market for solar thermal self-sustaining. These activities should ideally be supported by regional centres, working in the local language and in close contact with the local market.

9.2 Process heat collectors

The research infrastructure available for the research and development of process heat collectors is barely adequate.

Some research institutes are broadening the scope of their work in high temperature collectors for solar thermal power generation to include process heat collectors (for example, CIEMAT in Spain, and DLR in Germany), while others are coming at process heat collectors from a background in low temperature collectors (for example, Fraunhofer ISE in Germany, AEE INTEC in Austria, SIJ in Germany, SPF in Switzerland and INETI in Portugal).

No testing facilities specifically designed for process heat collectors exist in Europe today. The Joint European Solar Heating and Cooling Laboratory (outlined above), could be the place to test new components for medium temperature applications in outdoor conditions and serve as a centre for networking and information-sharing among members of the research community.

9.3 Heat storage

As discussed above, the development of advanced thermal storage technologies presents substantial R&D challenges. The broad scope of this work should ideally be addressed on a European scale with different industrial sectors (solar thermal, cogeneration and district heating) involved where relevant.

The launch of a virtual or real **"European Institute for Thermal Energy Storage"** would be helpful. It could help:

- scientists to work at each other's facilities, or visit them
- Scientists to share research infrastructures (testing equipment and communication tools)
- Strengthen MSc and PhD courses in solar thermal by accessing Europe's leading experts in this field

Through the outstanding reputation of the European Institute for Thermal Energy Storage it will be much easier to attract specialists from other important research fields, especially materials scientists. The contribution of other fields is of key importance to open up new ways for arriving at more compact thermal energy storage systems.

An institute also better supports the long term challenge that compact thermal energy storage poses. Only with a long term programme it is possible to couple basic science with applied science and engineering. The institute is one of the pillars for such a progamme.

The research infrastructure necessary for the institute ranges from specialised analytical equipment for materials research and development, through computing facilities for specialised numerical modeling technology developments, to dedicated equipment for component and system testing at medium and high temperatures.

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