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Scientific Assessment in support of the Materials Roadmap Enabling Low Carbon Energy Technologies:

Concentrating Solar Power Technology

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Scientific Assessment in support of the Materials Roadmap Enabling Low Carbon Energy Technologies:

Concentrating Solar Power Technology

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Preamble

This scientific assessment serves as the basis for a materials research roadmap for concentrating solar power technology, itself an integral element of an overall "Materials Roadmap Enabling Low Carbon Technologies", a Commission Staff Working Document published in December 2011. The Materials Roadmap aims at contributing to strategic decisions on materials research funding at European and Member State levels and is aligned with the priorities of the Strategic Energy Technology Plan (SET-Plan). It is intended to serve as a guide for developing specific research and development activities in the field of materials for energy applications over the next 10 years.

This report provides an in-depth analysis of the state-of-the-art and future challenges for energy technology-related materials and the needs for research activities to support the development of concentrating solar power technology both for the 2020 and the 2050 market horizons.

It has been produced by independent and renowned European materials scientists and energy technology experts, drawn from academia, research institutes and industry, under the coordination the SET-Plan Information System (SETIS), which is managed by the Joint Research Centre (JRC) of the European Commission. The contents were presented and discussed at a dedicated hearing in which a wide pool of stakeholders participated, including representatives of the relevant technology platforms, industry associations and the Joint Programmes of the European Energy Research Association.

Contents

1. STATE OF THE ART AND CHALLENGES

1.1. Reflectors

Status

Reflectors are used in all CSP technology branches: dish, tower, trough and Fresnel systems (an alternative concentrator could be lenses but this is not seriously pursued). Dish and trough typically use only “primary reflectors” i.e. there is one reflection to concentrate the sunlight on the absorber, whereas some tower and Fresnel designs use an additional “secondary reflector” close to the absorber to enhance the optical concentration. The Cassegrain design in the family of towers uses an additional elevated reflector to redirect the reflected light to a receiver closer to the ground instead of on top of the tower. Primary and secondary reflectors have different requirements in terms of temperature stability and specularity. Current state-of-the-art reflectors have a specular energy reflectance of 93 to 94% with an expected useful life of 20 to 25 years without excessive corrosion and UV degradation.

Thick glass mirrors: The most commonly used reflectors are made of silver-coated float glass or tempered float glass with a glass thickness of between 3 and 6mm. Corrosion of the silver is prevented by use of copper and of special coatings (lacquers). Mounting is typically with glued ceramic pads but other methods of purely mechanical fixation are used. In troughs, and also some heliostat or dish designs, the float glass is thermally bent (and possibly tempered) so the mirror holds its parabolic shape by itself. Other designs, especially Fresnel and tower with long focal length use mechanically bent flat glass that is kept in its parabolic shape by a rear support structure.

Laminated glass mirrors: the reflecting silver coating is protected between two glass panes. Here the backside protection of the silver is very good but reliable edge protection and prevention of delamination are still challenges.

Thin glass: silver-coated glass with a thickness of typically 0.5 to 1.0 mm is laminated on a support structure (steel, aluminium, polymer, glass). This solution is currently mostly used for dishes, and is also being considered for troughs. The main advantages are a high specular reflectance, a high mechanical flexibility and a good resistance to scratches.

Aluminium: aluminium sheets are coated with highly reflecting layers of aluminium or silver, protected by transparent scratch resistant coatings. This solution is lightweight, and can be easily shaped to any curvature. It is used for secondary reflectors and small parabolic troughs.

Polymer foil: a high-reflectance foil made of multiple layers of polymers with alternating refractive indices is laminated on a support structure (typically metal sheet). This solution is lightweight, and can be used in any curvature.

Stretched membranes: this concept, in which the parabolic shape is achieved by applying a partial vacuum to one side of a reflecting membrane, was mainly developed in the 1980s at NREL and Sandia. Some activity is still ongoing but no major industrial players are involved.

Challenges

- One of the challenges for glass reflectors is to reduce the lead content in protective coatings to address environmental concerns. While lead-free systems are extensively used for indoor applications, their durability outdoors is still a challenge.
- For solutions not using glass, surface durability (resistance to abrasion) is still either a challenge or in need of long term validation. Also the long term validation of corrosion resistance is of concern.
- Common issues for all reflectors are:
  - Increase of size – mainly an industrial issue.
  - Development of coatings with reduced maintenance requirements in the field. Indeed, reflectors need to be cleaned regularly to maintain efficiency. With the foreseen deployment of CSP in desert areas, there is a clear need for coatings that require less intensive maintenance, both in terms of labour and water.
  - Improvement of coatings with higher mechanical stability.
  - Development of standards for accelerated ageing tests, which would facilitate adoption of new developments. Such standards should take into account the different requirements for coastal, industrial/urban and desert climates.
  - Development of techniques to monitor and assure quality with respect to yield and detection of microdefects.

1.2. Absorbers

Status

Each type of CSP plant has its own absorber design.

Parabolic troughs use linear receiver tubes. The receiver is composed of an external glass tube (coated to ensure high solar transmittance) and an internal metallic pipe (coated to ensure high solar absorption and low infra-red emittance). Both parts are sealed together (metal/glass sealing). The space between the glass tube and the metallic pipe is evacuated to reduce heat losses from the pipe (a getter is included to maintain the vacuum). Most of the receiver tubes currently in operation have a diameter of 70 mm, use synthetic oil as heat transfer fluid (HTF) and operate at a maximum temperature of approximately 400°C. Developments are mostly related to the use of larger tubes (90 mm diameter or more) and high operating temperatures through the replacement of synthetic oil by direct steam or molten salt.

Towers use central receivers. The towers currently in operation in Spain (PS10 and PS20) have a so-called cavity receiver, formed of 4 vertical metallic panes in which saturated steam circulates. The panes are coated to increase solar absorption and arranged in a semi-cylindrical shape to minimise radiation and convection losses. The steam can reach up to 250°C. In USA, BrightSource is building a 400 MWe system with superheated steam at 550°C, using a traditional boiler as receiver. The recently inaugurated 19 MW Gemasolar tower plant in Spain uses molten salt as heat transfer medium to produce steam at 565°C. The salt circulates through metal tube receivers. In the "Solar Tower Julich" demonstration plant in Germany, a monolithic ceramic absorber material is used in a semi-cylindrical receiver design to produce heat for a steam process. The absorber material has to withstand temperatures of up to 800°C. Other R&D projects consider concepts for even higher temperatures making use of Brayton cycles with closed volumetric receivers (Solgate; Heller et al. (2006), Sugarmen et al. (2003)). Here porous ceramic materials are used that may reach locally 1200°C or even more. For smaller Brayton systems, metal tube receivers for exit temperatures of approx. 800°C are under development (profiled multi-layer absorber tubes, Amsbeck et al. (2010)). For fuel production (hydrogen), coatings on ceramic substrates are used as catalysts in first prototype receivers. These have to withstand more than 1200°C.

Fresnel systems also use linear receiver tubes. Tubes similar to those in parabolic trough plants can be used for systems operating in a similar temperature range (with steam replacing oil as HTF). Tubes are often not encapsulated in vacuum tubes, thus ambient air, moisture or dust can have contact with the absorber coating, which causes stability problems, especially at high temperatures.

Dish designs also use a central receiver which is designed to transfer directly or indirectly the solar energy to a Stirling engine (transforming heat into momentum, and momentum into electricity). Receivers are integrated with the Stirling engine to form the power conversion unit. Tubular receivers use high temperature alloys with surface temperatures of the order of 850°C and even higher at flux peaks. Internal pressure is approx. 150 bar. Cylinder head materials are operated at the same temperatures as the gas in the engine, i.e. at 650°. The header is made of another relatively exotic alloy with high cobalt content.

<u>Challenges</u>

A common challenge for all absorbers is to operate at higher temperatures and to allow for higher radiation fluxes in order to improve the efficiency of the solar-to-electricity conversion.

- For linear absorbers, this translates into the need for development of larger absorbers (essentially an industrial issue), the possibility to function with alternative HTFs and the development of selective coatings performing at higher temperatures than currently used.
- For central receivers and dishes, this implies the development of high temperature resistant materials and coatings.

1.3. Structural Components

<u>Status</u>

Structural components have the function to allow the precise orientation of reflectors and receivers and transmit the forces from a drive system to the optical components. Today, mirrors are mainly mounted on space frames or sandwich structures. Drives are attached to pylons connected to concrete foundations. In troughs, flexible joints are used to bring the heat transfer fluid from the ground to the focal line where the receiver is placed. Bearings are needed to move the concentrator structure.

Structures: Most plants today are parabolic troughs with a space frame (LS-3, Eurotrough type) or torque tube design with cantilever arms (Sener, Albiasa). The space frame is made of standard galvanized metal tubes or struts, which are connected by welding, screws, bolts or rivets with the help of a mounting jig. Newer designs use stamped cantilever arms from thin galvanized metal sheets. For heliostats similar techniques are used. Materials for the mirror support structure are mainly galvanized beams, struts, tubes, attached with the help of jigs. The complete structure is fabricated on site in an assembly workshop and transported with vehicles into the field and bolted/screwed/welded to the pylon structure. The manufacturing process is still mainly done by hand, although some manufacturers have started to use robots. Another construction type is based on composites, mainly fibre reinforced resins or even aluminium sandwich materials. The thickness of the sandwich, the type of fibres and the core material determines the stiffness of the structure. Mirrors that need shaped substructures, e.g. films or thin glass mirrors, can be integrated with the structural element.

Receiver holders in troughs need to keep the receivers in the focal line and compensate thermal expansion. In tower plants, concrete or space frame structures hold the receiver or even the turbines and generators at the desired height over the ground. Access is by stairs or elevators.

Drives are mounted on a base structure, normally a tubular pylon (metal or concrete), which needs high stability and rigidity. Dishes and some heliostats use turn tables based on rails or concrete rings. In such cases, wheels allow the structure to move on the base, normally requiring a central bearing. Generally, bearings transmit the movement from the drives to the structures and must be precise, durable, require little maintenance and have low friction.

In troughs, **ball joints or flexible hoses** are the linking element between the fix drive section and the movable concentrator. These are designed so as not to introduce additional forces on the structure and must be leaktight to avoid possible environmental risks.

Corrosion protection of the structures is done by prior galvanisation. If not galvanized they are pre-painted before welding and then painted on site. The use of aluminium or stainless steel avoids corrosion, but prevention from galvanic corrosion has to be ensured. In glass fibre designs corrosion is normally not of concern. But newer designs involve additional metal stiffening elements combined with the glass fibre structure.

Foundations are usually made from concrete, which has to be protected against aggressive minerals in the ground water at some sites (by use of paints and additives). Some heliostat designs use screw foundations, while others place the structure on the ground without foundations.

Challenges

The type of structure normally used in troughs and heliostats (space frame) requires precise fabrication, mounting and alignment. For optical precision during operation the structures need extremely high torsion and bending stiffness (space frame and sandwich), no backlash, no stick-slip, low friction, no creeping. Reduction of manufacturing cost implies use of low cost materials, minimum mass, and for manufacturing moulds, jigs, or robots. Quality assurance tools are often used prior to final mounting on site. A new, specific design code for CSP structures would avoid over-dimensioning and drive weight and costs down.

For support structures in large scale tower receivers, which are exposed to elevated temperatures, minimum deflections and a long term mechanical stability is required.

Generally, quality control of structural components materials, manufacturing process, and assembly may also drive cost down.

1.4. Heat Transfer Fluids

Status

Heat transfer fluids (HTF) are used in all CSP technology branches: trough, Fresnel, tower and dish. Their key function is to transfer the heat generated within the linear or the central receivers to the power conversion unit(s),

For **parabolic troughs,** the state-of-the-art is a synthetic oil with a maximum temperature of about 400°C. Higher operating temperatures result in formation of oil decomposition products which need to be removed more frequently. Developments mostly target improved synthetic oil, molten salts or steam, which allow higher temperatures. Molten salts have the disadvantage of high freezing points, whereas steam requires the development of receivers and flexible hoses and joints capable of withstanding higher pressures.

Fresnel systems can also use synthetic oil. However, as the absorber design results in less flexible hoses and moving parts, it seems a good candidate for adoption of water/steam as HTF and for withstanding the high pressures of superheated steam (100 bars, 500°C).

The higher concentration ratios of **tower** (or multi-tower) designs allow temperatures above 1000°C provided adequate receivers and fluids can be used. Molten salts were used in the range of 500-600°C in the first R&D projects (Themis in the 80s, Solar Two in the 90s). Current developments focus mainly on superheated steam at 550°C and still on molten salt technologies (Gemasolar). But gases such as air, hydrogen, helium and CO_2, as well as liquid metals, are also candidates for investigation.
.
Dish systems can also reach high temperatures. They are often associated with a Stirling engine with a gas working fluid (hydrogen or helium). The typical upper temperature is around 650°C. The gas itself is not of any concern for overcoming today's temperature limits in Stirling engines.

Challenges

Whatever thermodynamic cycle is used (Rankine, Brayton, Stirling), the higher the operating temperature, the higher the overall efficiency of the solar power plant.

However, increased operating temperatures may be detrimental to the thermal stability and raise the cost of the HTF. Therefore, what is at stake is to achieve a reasonable compromise between overall plant efficiency, material properties (safety, stability, durability) and cost when developing new formulations

- For linear absorbers, this translates into the development of fluids that exceed the current temperature threshold of 400°C, going up to 550-600°C. For molten salts, it also means to decrease their freezing point.
- For central receivers and dishes, which have even higher operating temperatures, molten salts, liquid metals and gases have to be investigated. Corrosion resistance should also be addressed.

Of course, operating temperature is not the only criteria, and a trade-off between many other parameters has to be made: toxicity, flammability, corrosion resistance, rate of decomposition etc.

Accelerated ageing test procedures are also important to characterize their degradation rates or the corrosion process in other components such as receiver tubes.

1.5. Heat Storage Materials

Status

In CSP plants thermal storage is used to store the heat from the solar field prior to its reaching the turbine. Storage systems studied today take the form of sensible or latent (Gil et al., 2010; Medrano et al., 2010), although commercially only sensible systems are used. The solar field needs to be oversized so that enough heat can be supplied both to operate the turbine during the day and, in parallel, charge the thermal storage. Thermal storage needs to be at a temperature higher than that required for the working fluid of the turbine. As such, these systems are generally between 400° and 600°C, with the lower end for troughs and the higher end for towers. Allowable temperatures are also dictated by the limits of the storage media.

Examples of storage media include molten salt (presently with separate hot and cold tanks), steam accumulators (for short-term storage only), ceramic particles, high-temperature phase-change materials, graphite and high-temperature concrete. Another type of storage associated with high-temperature CSP is thermochemical storage, where solar energy is used to make a fuel (Steinfeld and Meier, 2004).

Today most CSP plants use steam accumulators to meet the requirements for short-term buffer storage, providing saturated steam at pressures up to 100 bar (Medrano et al., 2010). They profit from the high volumetric storage capacity of liquid water for sensible heat (up to 1.2 kWh/m^3) and the experience of operating similar storage systems in fossil fuel fired facilities over many decades.

Recently several reviews have identified long lists of potential materials to be used as storage materials for CSP plants (Gil et al., 2010; Kenisarim, 2010; Nomura et al., 2010).

Concerning solid materials for sensible heat storage systems, concrete and castable ceramics are the most studied, due to their low price and good thermal conductivity. Both have been tested at the Plataforma Solar de Almeria and have demonstrated good characteristics for such applications (Lovegrove et al., 1999; Tamme, 2003).

A variety of fluids were tested for transporting the heat, including water, air, oil, and sodium, before molten salts were selected as best. These are used in solar power tower systems because they are liquid at atmospheric pressure, provide an efficient, low-cost medium in which to store thermal energy, their operating temperatures are compatible with today's high-pressure and high-temperature steam turbines, and they are non-flammable and non-toxic. In addition, molten salts are used in the chemical and metals industries as a heat-transport fluid, so considerable experience exists (Kearney et al., 2006; Sena-Henderson, 2006). Recently, the price of molten salts has increased considerably, questioning the economical viability of new plants. Other challenges for their use are corrosion, chemical stability and the high melting temperature which leads to high parasitic electrical expenses.

Storage systems based on phase change materials (PCMs) with a solid-liquid transition are considered to be an efficient alternative to sensible thermal storage systems. Nowadays there are a few commercially available PCMs, but these still have too low a phase change temperature; however there are others that could be used (Gil et al., 2010; Kenisarim, 2010; Nomura et al., 2010). PCMs present other problems that must be overcome, such as low thermal conductivity and build-up of solid deposits on the heat transfer surfaces. Both of these translate in a reduction of discharge rates.

Exploitation of the heat of chemical reactions has the possibility to realize higher efficiencies than other thermal energy storage technologies (Van Berkel, 2005), the main advantage being the potentially high energy density.

The piloting of new storage concepts (such as concrete storage, PCM, etc.) is currently held back by the difficulty to get the adequate insurance, which in turn is a pre-requisite to obtaining funds from banks. Therefore, for any new storage technology to reach the market, more demonstration plants are needed, as well as the standardization for new testing procedures.

Dish systems do not currently use storage systems, but research on PCM storage and helium systems is being performed.

Research on storage systems should not neglect the container materials. Today there are no materials (steels or other alloys) cheap enough to be introduced in CSP plants. Moreover, most of the studied storage materials are corrosive and work at high temperatures, which seriously limits the performance of much today's container materials. Such research should therefore include also new protective coatings.

Challenges:

The main challenges for heat storage materials are:

- New storage materials/systems
- Standardization of new storage materials/systems
- New container materials/systems

1.6. Other Components and Systems

Heat exchangers: Today's molten salts storage systems for CSP plants use a heat exchanger to transfer the heat from the HTF of the solar loop (usually thermal oil) to the molten salts. The high corrosivity of these molten salts, together with the high temperatures used pose problems for the selection of heat exchanger materials. New materials able to work in these severe conditions are needed, to give the systems a longer life.

Heat exchangers are also used in Brayton cycle systems (towers or dishes). The requirements for higher operating temperatures are a challenge for the heat exchangers seals and construction materials. Structural ceramics for higher temperatures applications that can also withstand higher differential pressures could be a solution.

Process Heat applications

CSP technologies have a high potential to replace fossil fuels in process heat applications such as

- the direct use of solar generated steam in production processes, e.g. in the food, textile, or chemical industry.
- desalination of sea water or brackish water. The typical operating temperature of thermally driven desalination units is at max 120°C and can be as low as 70°C, which makes this technology suitable for using, for instance, the waste heat of a turbine in cogeneration systems.
- solar cooling, where operation temperatures of 180°C to 250°C allow for the use of high efficient cooling technologies like double or triple effect absorption chillers.
- micro CSP and cogeneration systems, which close the gap from large centralized CSP to small scale decentralised installations of several tens of kW

Most challenges for process heat applications are on the system integration side but there are also a number of materials related challenges. These cover the components described above but sometimes have different boundary conditions due to generally lower operating temperatures.

Dry cooling

The consumption of water for cooling of the thermal cycle is of concern since CSP will have its market in desert areas with scarce water resources. The technology for dry cooling is seen as mature since it has been used for many years in the power industry. Nevertheless the cost for dry cooling is significant higher than for wet cooling.

Construction and deployment

For cost reduction of power plants novel techniques are needed to reduce manual construction work and achieve a higher degree of automation. This should include easier maintainability and replacement of malfunctioning parts in particular in the field.

2. MATERIAL SUPPLY STATUS AND CHALLENGES

2.1. Reflectors

Main materials

Substrate. The main material currently used is glass, which is widely available all over the world. The raw material is abundantly available (sand), and float technology is already widely used. To produce glass for solar applications, it is important to use raw materials (sand, but also dolomite and limestone) with very low iron content to arrive at so-called “extraclear” glass, which has higher energy transmittance than the regular “green” glass. As already explained, alternative substrates for reflectors are metal and polymer sheets, which are also widely available.

Silvering. During the silvering steps for glass reflectors, cerium is used to clean (mechanically and chemically) the surface, on which successive layers of silver, copper and up to 3 paint coats are applied.

Challenges

Low iron materials. Even if there are some temporary tensions for the availability of these raw materials, it is not expected that material supply will be a problem even with a high growth scenario. Raw materials suppliers have developed or are developing techniques to reduce the iron content of the raw materials (e.g. attrition, magnetic separation, flotation, leaching). Their implementation is dependent on the premium that can be accepted by the market. On their side, glass producers are also developing techniques aiming at reducing the negative effect on the energy transmission of the remaining iron in the glass. It has to be noted that the same raw materials are also used to produce solar glass for the photovoltaic industry (where the quantities needed are, and should remain, higher by at least an order of magnitude).

Cerium is currently mostly supplied from China, and as rare earth material is also used for catalysers. There is, therefore, some risk of a shortage if China were to limit its use to its own industries (this shortage is already currently a reality). Cerium is not easily replaceable in the silvering process.

Silver is currently subject to speculative tensions (with prices having more than tripled the last few months). However, it is not expected that this could cause a shortage as the market of silver is 20,000 tons per year and CSP requires only 50 tons per GW capacity (Andasol type with storage).

Copper is used in solar mirrors to block UV transmission. It's supply is subject to market speculation and its availability might be an issue in the long term, given the number of applications where this material is used.

Paints. As already explained, one of the main material challenges for reflectors is the reduction of lead in protective paint layers due to environmental concerns.

Recycling. In the event of a large growth of the CSP segment, it may be interesting to develop a recycling path for the reflectors (with separation of substrate, silver, copper and paints).

2.2. Absorbers

Materials

Linear receivers (for Trough and Fresnel). The basic materials of linear receivers are glass and metallic pipes, and their supply is not really at risk. The anti-reflective coatings and spectrally selective coatings (CERMET) use standard materials (SiO_2, TiO_2, Cr, Mo, Al_2O_3, etc.). The key elements are more in the design of multilayer coatings, and in their associated production technologies, namely (1) the coating deposition used for the glass and the pipe, and (2) the glass-metal sealing. Barium is used as a getter material to bind the hydrogen diffusing through the metal wall and thus maintaining the vacuum.

Tower receivers use metal and ceramics as base materials.

Dish receivers are typically exposed to high temperatures and require the use of special alloys.

Challenges

Linear and central receivers do not typically use materials for which a lack of availability is feared.

The challenges for **linear receivers** are more linked to:

- The need to adapt the metallic pipe to the different HTFs (from oil to steam, molten salt, …), and the possible need to develop special protective coatings for these.
- The development of spectrally selective coatings on the metallic pipe to withstand higher temperatures, while keeping the same or lower emissivity and absorptance.
- The development of selective coatings to withstand natural weathering (air, dust, humidity) in the case of non-evacuated receivers for Fresnel applications.
- The development of materials for the secondary reflector to withstand high thermal loads and natural weathering (air, dust, humidity) in the case of receivers for Fresnel applications.

The challenges for **central receivers** are linked to:

- The development of specially designed high temperature metals or ceramics to fully exploit the potential of the technology. The supply of ceramics such as silicon or aluminium oxides for high temperature absorbers is not seen critical. Spectrally selective coatings to be applied on such materials need to be further developed in order to achieve lower degradation rates and higher optical performance, but may rely on the same principal materials as those of today. For fuel production specific catalytic coatings are required to withstand high temperatures, but these not a supply concern.

Dish receivers use high-end alloys for which both the availability and the development may be more complex and which may be sensitive to shortages.

2.3. Structural components

<u>Materials</u>

Collector structures for space frames from steel or aluminium are generally not of concern because the materials are widely available. Quality control for very low cost materials is necessary.

Fibre reinforced plastics: Fibres and resin materials are widely available. Large structural components require expensive moulds and enormous manpower, and only a few manufacturers are prepared for this due to the small market.

Flexible joints: There are 4 principal manufacturers on the market. Material supply is not of concern. Quality control to minimize leakage rate and increase life time is necessary, especially for higher fluid pressures and temperatures.

Bearings: standard component, no supply limitations.

Foundations: Concrete is not of concern, additives and protective paints are available in all countries of interest.

<u>Challenges</u>

Quality control for low cost materials.

2.4. Heat transfer fluids

Materials

Considering available resources, there is no real availability problem for the widely used fluids: synthetic oil, traditional salts or gases.

For the most common trough technology, several manufacturers propose a synthetic aromatic fluid, based on biphenyl and diphenylether which decomposes at temperatures higher than 400°C

<u>Challenges</u>

Supply problems could arise when developing new fluids e.g. salt mixtures with significant content of new material or synthetic oils with new formulas. Gases such as hydrogen, helium, air, CO_2 do not pose any supply concern.

2.5. Heat storage Materials

Materials

Only molten salts are commercially available at present, with a nominal composition of 40% $NaNO_3$ and 60% KNO_3. Commercially, they are marketed as HitecXL, a ternary salt consisting of 48% $Ca(NO_3)_2$, 7% $NaNO_3$, and 45% KNO_3. This was developed as a derivative of Hitec (a eutectic mixture of 40% $NaNO_2$, 7% $NaNO_3$ and 53% KNO_3, with 142 ºC melt-freeze point) (Pilkington, 2000 and Foster, 2002).

When looking at heat storage materials for CSP plants, one should not neglect the container materials. Currently the operational temperatures (maximum of 380 ºC) mean that conventional steel can be used, although there are still issues on corrosion protection that are being addressed at research level.

Challenges

Suppliers of $NaNO_3$ and KNO_3 are also those supplying these salts as agricultural fertilisers. This new CSP application means a new market for the suppliers, but also market competition for farmers and the increase in demand has meant a price increase.

Supply problems could arise when developing new fluids (salt mixtures with significant content of new materials)

Today there are few suppliers of molten salts. This shortage of suppliers compromises cost and supply security for new CSP plants. Development of new materials could solve this.

Steam storage is a state of the art technology and has no supply chain problems, especially not for materials.

No material supply chain problems are foreseen for container materials, as the steel grades used are available worldwide.

2.6. Others

Heat exchangers: Today stainless steel is used in solar heat /storage heat exchangers. No material supply chain problems are foreseen. Nevertheless, if high temperature alloys are to be used in the future, cost is considered to be the main problem.

Drives: For the gears hardened steel is used, which is widely available. Electrical motors have a high content of copper, which is sensitive to market shortages which influence cost.

3. On-Going Research and Challenges

3.1. Reflectors

Ongoing R&D

The overall aim of reflector research is to reduce total costs and is mainly achieved through (1) improvement of specular reflectance, (2) improvement of the geometric precision of the concentrator (in two- or three-dimensionally curved shapes), (3) reduction of the weight of the reflectors and their integration into the structure, and (4) development of anti-dust / anti-soiling systems. In addition, research is ongoing in order to reduce the amount of lead used while maintaining good resistance against corrosion and UV degradation. For secondary reflectors used in tower or Fresnel receivers, resistance to high temperature degradation becomes important.

The major industrial glass players are active in this field, namely Flabeg and Rioglass, but also traditional float glass producers such AGC, Guardian, PPG and Saint Gobain, as well as paint manufacturers such as Valspar and Fenzi, and specialty chemical companies such as Ritec.

For metal sheet reflectors ongoing developments are directed towards the use of silver as front surface reflecting material and to transparently coat it with sufficient chemical and mechanical protection to give long outdoor lifetime. Corrosion or delamination between layers is still a concern for long term stability. Actors involved are Alanod, Alcan, Almeco and Hydro.

For polymer foil reflectors, the long lifetime with mechanical and chemical stability and also UV stability is a big challenge. Actors are 3M and Skyfuel/Reflectech. These companies are also carrying out material research in the field of surface treatments to enhance the cleaning of reflectors (self cleaning surface), as well as to find automated cleaning methods t tailored to these specific surfaces and causing the least damage.

R&D institutions involved in all such material research are CIEMAT, CNRS, DLR, ENEA, Fraunhofer ISE, NREL and Sandia.

Some studies are ongoing in the field of accelerated aging. This includes basic research as well as applied research to speed up the market introduction of new materials and to develop quality standards and testing procedures. The main actors are Ciemat, DLR and NREL.

Challenges

While R&D on reflectors faces considerable challenges, these are mostly dealt with by the existing industrial players. More basic research is probably needed for anti-soiling / anti-dusting coatings and for development of quality standards / testing procedures.

3.2. Absorbers

Ongoing R&D

Trough receivers in commercial operations are currently supplied by two European companies, namely Schott Solar and Siemens (through the acquisition of Solel). Both are working towards the increase of the diameter of the tubes, and for the replacement of the HTF oil by direct steam or molten salt. In addition to these dominant players, Archimedes Solar (45% owned by Siemens) is developing receivers using molten salt. Competition is also starting to develop from China.

Fresnel receivers are developed by three European companies, namely Schott Solar, Areva (through the acquisition of Ausra) and SPG/MAN Ferrostaal.

Tower receivers are being developed either directly by the main European and American technology developers (e.g. Abengoa, Sener, BrightSource, eSolar, Solar Reserve) or in collaboration with other companies (such as boiler developer Riley Power in the case of BrightSource, PwR in the case of Solar Reserve, or ceramic material developers for high temperature operations). The main objective is to replace saturated steam with superheated steam (BrightSource, Abengoa), molten salt (Sener), non-pressurized (KAM) or pressurized air (Abengoa, Aora) or solar fuels.

Dish power conversion units are being developed by European and American companies (mainly SBP, Cleanergy, Tessera Solar and Infinia) in collaboration with Stirling engine suppliers. The temperatures are as high as possible, therefore involve costly alloys which may be sensitive to raw material shortages.

In addition to the above companies, the R&D organisations involved include CIEMAT, CNRS, DLR, ENEA, Fraunhofer ISE, NREL and VTT.

The research mainly focuses on the following:

- **Coatings** developed for the currently available linear receivers in evacuated tubes are generally considered to be already reaching their physical limits. Besides a marginal increase of the transmittance, absorptance and emittance, most improvement is expected to come from the possibility to maintain these properties while operating at higher temperatures. This is being investigated by Schott Solar, Siemens and Archimedes, Fraunhofer ISE.
- **Coating** able to withstand high temperatures and natural weathering in atmospheric conditions (non evacuated) are at a less mature state of development.
- **Ceramic** materials to exploit the full potential of tower technology are finally being developed for central receivers by technology and materials developers (Abengoa, Sener, BrightSource, KAM, Saint Gobain, Schunck) or material developers (e.g. Saint Gobain).
- Metal tubes for temperatures as high as 850°C based on Profiled Multi-Layer tube technologie (DLR, Turbec, Abengoa, GEA, etc.)
- Catalyst coatings for the production of fuels in high temperature processes based on ferrites.
- Direct Irradiated Receiver (DIR) technology based on particles as absorbers. Initial work has been started on prototypes (SANDIA, DLR).

Additionally basic research is being carried out to better understand and simulate the ageing of receiver tubes for towers or linear receivers (including the H_2 diffusion from the synthetic oil), notably by DLR, Ciemat and CNRS in the European SFERA project.

Challenges:

Achieving high performance with open systems in central receivers means high temperatures and large specific surface areas. Both yields high risks especially regarding operation lifetime. Research on shape forming of high porosity ceramics and high temperature metals is needed.

3.3. Structural components

Ongoing R&D

Research on structural components is performed for new collector designs. Larger structures, higher precision, higher operating temperatures and pressures are currently the focus of interest. Work is under way at several European engineering and construction companies (Solar Millennium, ACS-Cobra, Iberdrola, Flabeg, Siemens, Acciona, SBP, etc.).

The use of new materials such as fibre reinforced plastics or aluminium to reduce cost is under way or planned (SBP Solarlite, NEP, Solitem, ENEA/Archimedes). Solarlite has initiated a manufacturing line in Thailand for trough elements from fibre reinforced materials to enhance the structural performance at low cost. Research work for complete lightweight aluminium structures involving the reflector panel as a structural component had been proposed but is not yet funded (Almeco, Alanod, Alcan).

For ball joints and flexible hoses industry is putting a lot of effort into guaranteeing performance for higher temperatures and pressures. Especially for direct steam generation, the graphite sealings offered by the major suppliers have been tested and improved (ATS, EZM). For flex hoses the cost must be reduced (Senior Berghöfer). To reduce field piping costs, linear compensators are being developed to replace lyra bows.

Developments on heliostat drives focus on reducing cost by a reduction of mass, wear and tracking inaccuracies (Sener, Pujol-Muntala, Siemens Geared Motors). Since an optimum size for heliostats is not yet established, small heliostats with mass-produced cheap drives compete with large heliostats with high precision drives.

Automatic assembly by robots is being developed by Novatec-Biosol for the Fresnel reflector panels.

Challenges

- Development of larger structures providing sufficient stiffness to increase plant efficiency at lower structural cost
- Introduction of new composite materials to lower weight, handling costs and to optimize materials structural characteristics
- Increase automation

- New concepts for large structures with high performance under wind forces
- Measurement and simulation of wind forces: improve wind load models; verfication by field measurements

3.4. Heat transfer fluids

Ongoing R&D

The main on-going research activities are:

- Direct steam generation is being developed on demonstration level by Schott, Siemens, Solar Millennium, Iberdrola together with research instititues
- Development of several new HTF formulations with improved characteristics:
  - Improved synthetic oils, with a better heat transfer coefficient by Dow and Solutia
  - Molten salt systems (sodium nitrate / potassium nitrate) by Schott and Archimedes Solar (linear receivers), by Sener (central receiver) and by Coastal Chemicals and Halotechnics in the USA.
  - Alternative inorganic materials with lower freezing points than molten salt are being developed by for instance. Dow Corning.
- R&D organisations such as CIEMAT, CNRS, DLR, ENEA, Fraunhofer ISE, CEA-INES in Europe, NREL and Sandia in the USA and .CSIRO in Australia are involved in additional topics such as :
  - Nanoparticle enhanced HTF's (oil and molten salts) with the objective to improve heat capacity.
  - encapsulated PCM nanoparticles
  - metallic PCMs compatible with molten salt HTFs
- Facilities capable of performing :
  - fluid property measurements
  - interface studies: HTF / absorber, storage tank, PCM
  - Long-term field testing of fluid performance and stability

Challenges

- Improved HTF formulations with :
  - Increased thermal stability to temperatures over 400°C for oil-based HTFs (avoiding hydrogenation) or to over 500°C for molten salts
  - Melting points below 100°C. This can be improved by means of alternative molten salt formulations, for example by varying the nitrate/nitrite ratio and the concentration of components such as lithium, sodium, calcium and potassium.

- Development of :
  - models to predict the main properties such as heat capacity, melting point, heat of fusion, and density
  - characterization methods to check as quickly as possible these properties and their ageing rates.

3.5. Heat storage Materials

<u>Ongoing R&D</u>

Research in CSP storage systems was carried out mainly in southern California (USA) between 1985 and 1991, but Europe took over in the '90s. Today, research has spread to other parts of the world.

Today in Europe research is driven mainly by national and industry projects. In FP6, the project DISTOR (Energy Storage for Direct Steam Solar Power Plants) was the only European funded consortium.

In FP7, the project HEAT SAVER (Development of a heat storage system to improve energy efficiency in CHP power plants and in solar driven industrial applications with high relevance to SME) included research on heat storage materials for CSP plants.

In 2010 there was an EC call, currently under evaluation, which will ensure that a new consortium will be created soon focussing on the development of new fluids.

The main European research institution working on heat storage materials are DLR (Germany), CNRS-PROMES (France), CNRS-TREFLE (France), University of Lleida (Spain), CIEMAT (Spain), University of Barcelona (Spain), Inasmet (Spain), Fraunhofer ISE (Germany) and the University of Nottingham (UK).

Industrial companies involved in heat storage materials research are Abengoa Solar NT and e-on. Other companies such as Acciona, Iberdrola and Sener are interested because of the impact that this research would have in their business development.

Challenges

The main challenge of R&D in materials for heat storage is to find or develop cheap materials with high energy density and good performance at high temperatures. Sensible heat storage needs new materials (short term possibilities), latent heat storage needs to be developed and implemented (medium term research), while thermo-chemical storage is the technology least developed but appropriate for long term research.

3.6. Others

On-going research in the field of CSP for process heat applications is generally more on the system integration aspects rather than on materials involved. Some important materials-related activities are however:

- Desalination: improvement of membranes for solar distillation technology that can be used in cogeneration systems as a heat sink. Development of materials that avoid fouling and scaling
- Solar cooling: new refrigerants for thermally-driven chillers, development of triple effect absorption heat pumps

4. MATERIALS' PERFORMANCE TARGETS

4.1. Targets for Market Implementation in 2020/2030

4.1.1. Reflectors

Recently, ESTELA (European Solar Thermal Electricty Association) and AT Kearney published targets for 2025. Building on the results of that study, the mid-term targets for reflectors can be defined as

- Specular reflectance: 95 to 96%
- Elimination of heavy metals in the final product
- Low maintenance anti-dust / anti-soiling coatings
- Total cost of ownership reduced by 25% compared to 2010, which is likely to necessitate a ramp-up of the volumes of CSP projects (production learning curve, economies of scale) and stronger integration between the reflectors and the structure

Reflector materials used for secondary concentrators (Fresnel, central receivers) should be high-temperature stable. Depending on the specific design, temperatures of up to 400°C should be possible.

Accelerated ageing tests should be developed to verify the specifications and loads.

4.1.2. Absorbers

Here again, the ESTELA / AT Kearney study provides good indicative targets for the coatings to be used in linear receivers, as shown in the following table:

Absorptance	Emittance	Transmittance	Max. temperature
> 96%	9% at 400 °C 10% at 450°C 14% at 580°C	> 97%	600°C

Indicative targets for the ceramic or metal materials used for the central receivers are:

- Potential to operate to 600°C (operation with molten salt)
- Potential to operate to 500°C/120 bar (operation with direct steam)
- Potential to operate at 1000°C in Brayton cycles

4.1.3. Structural components

Targets for collector structures:

- Collector aperture area to increase by 75%
- Specific cost reduction by 5%*
- Improve structural stiffness and performance at larger aperture areas by 1-2%
- Maintain contour precision of structures under temperature changes
- Allow for operation at higher wind speeds (target 17 m/s)
- Reduce cost for assembly of collector by 5%*

N.B. The cost targets here do not considering economies of scale)

Targets for flexible joints:
- For oil as heat transfer fluid: increase operation limits to 450°C
- For direct steam generation and molten salt systems: increase operation limits to 550°C

Targets for fibre reinforced materials:
- Implementation of stiffer fibre reinforced materials than glass at lower cost
- Reduction of shrinkage during hardening process by optimised resins
- Reduction of fabrication time by faster hardening
- Improve mechanical properties of composite structure
- Cheaper basic materials with better properties (strength, weight, chemical resistance)
- Reduction of mould costs by developing resins for hardening at lower temperatures (room temperature)

Targets for high temperature structural materials
- Allow higher temperatures, reduced cost, corrosive-resistant, higher pressure loads (steam/air)

4.1.4. Heat transfer fluids

Candidate materials must optimise the trade-off between many general criteria:
- Potential to operate continuously at higher temperatures
- Low viscosity, in order to reduce parasitic losses (at nominal temperatures but also at low temperatures)
- Possibility to be combined with heat storage systems
- Low freezing point
- Non-toxicity
- Low cost
- Specific gravity
- High heat capacity
- Sufficient pumpability
- Thermal cycling tolerance
- Sufficient long-term stability (low decomposition rate, low hydrogen emission)
- Chemical compatibility with common stainless steels or metals (corrosion)
- Low environmental impacts in case of leakage

Precise values of these parameters will depend on the specific application (linear or central receiver) and the type of material:
- For oil HTF : thermal stability beyond 400 °C (e.g. 450°C)
- For molten salt : freezing point below 100°C , with thermal stability up to about 500°C, with no phase separation problem.

4.1.5. Heat storage Materials

Targets for heat storage materials:
- Cost reduction
- Energy density increase
- Increase thermal conductivity
- Ability to work at higher temperatures (600 ºC)

Targets for container materials:
- Ability to work at higher temperatures (600 ºC)
- Cost reduction
- Corrosion resistance to molten salts

4.2. Targets for Market Implementation in 2050

4.2.1. Reflectors

- Specular reflectance: 96 to 98%
- Eliminate heavy metals from the final product
- Full recyclability of the reflectors
- Total cost of ownership reduced by 50% compared to 2010 situation, which is likely to necessitate ramp-up of the volumes of CSP projects (production learning curve, economies of scale) and stronger integration between the reflectors and the structure

4.2.2. Absorbers

Indicative targets for the ceramic materials used for the central receivers are:
- Potential to operate at temperatures up to 1200-1400°C (Brayton cycles and solar fuels)
- Potential to operate at temperatures up to 700°C (molten salts and steam cycles)

4.2.3. Structural components

Indicative targets could be to further increase aperture area to 150% of today's value and increase plant efficiency by 7%

4.2.4. Heat transfer fluids

Targets will be to further increase the operating temperatures, while keeping upfront and operational costs as low as possible.

4.2.5. Heat storage Materials

Targets for heat storage materials and container materials are further cost reductions, higher temperatures and increased thermodynamical/chemical properties.

5. SYNERGIES WITH OTHER TECHNOLOGIES

5.1. Reflectors

Obviously the float glass industry is active in product development not only for solar reflectors but for many other glass users e.g. the building and construction industry. Also here the requirements for optical quality and mechanical stability are rising (display windows, glass facades on high rise buildings). Facades and windows also need cleaning and research is ongoing for self cleaning surfaces.
PV module production needs large quantities of "extraclear"glass. Cleaning issues, mechanical and chemical stability are identical to those of solar reflectors.
Synergies with the automotive industry can be found in the requirements for weathering, UV and scratch resistance. All coatings, lacquers and other materials for bumpers, windshields etc. face harsh conditions that are quite comparable to those of CSP plants.
Aluminium reflectors are widely used in the lighting industry. Here the applications are mostly for indoor use but the optical quality has similar needs.
Automotive headlights use polymeric reflectors with high requirements on optical precision, lifetime and costs.

5.2. Absorbers

Linear receivers are extremely specific components. However, the coating technologies used are also relevant to other optical applications in the building, automotive and photovoltaic fields.

Central receivers can benefit from synergies with boiler technologies operating over similar temperature ranges.

In both cases, the materials knowledge developed for alternative heat transfer fluids such as molten salts with higher operating temperatures is also developed in other energy technologies (for instance the nuclear industry).

5.3. Structural components

Synergies for structural components exist generally with the automotive industry for manufacturing of low weight, high strength material structures using composite materials or aluminium. The materials and the design have to be suitable for automatic manufacturing and assembly. Synergies also exist with wind energy, where blades are designed from composites for optimum strength at low weight and low cost.

The construction industry has similar constraints for foundations (waterproof, corrosive working environment) and low cost tower structures, where high strength, light weight, weather proof materials properties are required.

The need to accommodate the daily thermal expansion cycle of components such as receivers using the flexibility of the structure has parallels in the conventional fossil and nuclear power industry.

5.4. Heat transfer fluids

The use of nanoparticles as additives in HTFs to enhance heat capacity is being pursued in several other fields where heat exchange is a key issue: computing, mechanical engines, process technology.

Synergies may also exist with other sectors where heat transfer fluids are used in large quantities, such as:

- 4^{th} generation nuclear reactors
- Hydrogen production facilities using high temperature cycles.

There are synergies between heat transfer fluid (HTF) and thermal energy storage (TES), since novel materials may be similar for both applications. However, the optimum HTF may not be optimum for storage applications: prices and operational pressure are additional criteria that have to be taken into account.

5.5. Heat storage Materials

Research in heat storage materials is much more developed for lower temperature applications. For example, solar systems for domestic hot water (DHW) or heating are being studied by many researchers. The main technologies considered are sensible heat storage with water (a very mature technology but with still some research needed, mainly in the tank design), latent heat storage with phase change materials (it seems that DHW systems are not the best application, but heating has potential) and themochemical storage (a very promising technology, but with a long way to go). Information can be found in several published books and reviews. Cabeza et al. 2011 summarises most of the recent reviews that can be found.

Solar cooling is a new technology that heat storage materials are being developed for. These systems has many synergies with storage for CSP, because the storage temperature is higher than 150 ºC and therefore similar challenges have to be overcome in both applications. An example of the research carried out today can be found in Helm et al. 2009.

The same can be said with the development of heat storage materials for industrial applications, especially for waste heat recovery in industries such as pulp, paper, metallurgy, cement, etc.

As for container materials, synergies with other technologies also working at high temperatures such as the fossil power and nuclear industries should be taken into consideration.

6. RECOMMENDATIONS

The CSP industry has set clear goals for concentrating solar power to make a significant contribution to Europe's future electricity supply, with high-scenario projections of 30 GW installed capacity by 2020 and 60 GW by 2030 (a further substantial contribution may come if the aims of the Desertec initiative are realised). A key factor to achieving sustainable market penetration for CSP will be reduction of the levelised cost of electricity. ESTELA envisages that 28-37% of the anticipated reduction in LCOE by 2025 will come from diminished plant costs and increased efficiencies. In both areas materials R&D will have a critical role to play, bringing benefits to customers and sustaining the leading role of European plant manufacturers and operators.

6.1. Market Implementation in 2020/2030

Table 1 summarizes the main issues identified for materials research and demonstration projects for plant design expected to come into commercial operation in the period 2020/203.

It is emphasized that materials qualification and performance standards is a common issue for all the component systems. While industry has primary responsibility for the development of the standards themselves, research institutions should be encouraged to collaborate more effectively on pre-normative issues. Examples include

- improved measurement techniques
- accelerated ageing and modelling activities designed to better understand the physical basis of degradation process, to support more reliable qualification testing and reliability.

Today Europe leads in research on thermal energy storage for CSP plants. This is due to the fact that USA stopped such research in the late 80’s and only Europe continued it. Institutions such as DLR in Germany have steadily continued their efforts, and in the last 5 years other groups such as PROMES-CNRS in France, the University of Lleida and CIEMAT in Spain have contributed. Even more recently, interest around the world has picked up, with the USA in particular making significant effort. The goals of the SET-Plan need to be backed up by appropriate institutional support from the EU and from the Member States to guarantee that technical leadership in this field stays in Europe.

Table 1 Main issues for materials research and demonstration projects relating to plant designs expected to come into commercial operation in the period 2020/203

Priorities for Near/Medium Term Materials Research for CSP Systems					
Component /system	**Materials**	**Aims & Issues**	**Proposed Research Action**	**Priorities (1=high 2=medium 3=low)**	**Time Scale (years)**
Heat transfer fluids	Alternative synthetic fluids	Increase operating temperature, long-term stability	Applied R&D (Project) Pilot action	1	0-3
		Degradation processes, accelerated testing	Applied R&D (Programme) Reference test facility and pre-normative research	1	0-3
		Measuring and simulation techniques for physicochemical parameters (density, vapour pressure, viscosity, heat capacity)	Applied R&D (Programme) Reference test facility and pre-normative research	2	3-6
	Molten salts	Improve operating temperature range, long-term stability	Applied R&D (Project) Pilot action	1	0-3
		Degradation processes, accelerated testing	Applied R&D (Programme) Reference test facility and pre-normative research	1	0-3
	Liquid metals	higher temperatures, better heat transfer, better chemical stability	Applied R&D (Programme)	3	6-10
	Gases	Higher temperatures and efficiencies	Applied R&D (Programme)	3	6-10
Heat storage	Solid ceramic particles, high-temperature phase change materials, Solid ceramic particles, graphite, high-temperature concrete	Thermal properties & reduced costs	Applied R&D (Project) Pilot action Demonstration actions	1	0-3
	Thermo-chemical energy storage materials	Development of new materials	Basic R&D (Programme)	2	3-6
	Higher temperature storage materials (at least 600 ºC)	Development of new materials, thermal properties, any technology	Basic R&D (Programme)	1	0-3
	Steels/composites/liners for piping and tank structures	Long-term resistance to internal corrosion and thermal strains	Pilot action Demonstration actions	3	6-10

Priorities for Near/Medium Term Materials Research for CSP Systems					
Component /system	**Materials**	**Aims & Issues**	**Proposed Research Action**	**Priorities (1=high 2=medium 3=low)**	**Time Scale (years)**
Absorbers/ Receivers	Spectrally selective absorber coatings stable both in vacuum and air	Increased absorptance, resistance to higher temperatures	Applied R&D (Programme) Pilot actions Demonstration actions Reference test facility and pre-normative research Market measures	1	0-3
	Metals	Long-term resistance to corrosion, increase temperature	Applied R&D (Programme) Pre-normative research	1	0-3
	Glass/alloy tubing for direct steam generation	Resist high temperature, pressure and thermal cycling	Applied R&D (Project) Demonstration actions	1	0-3
	Profiled multilayer-tubes	Higher temperatures, less stresses, longer life time	Applied R&D (Project) Pilot actions Demonstration actions	2	3-6
	Porous ceramic and metal structures for central receivers	Higher mechanical stability, higher temperatures, better performance	Applied R&D (Project) Pilot actions Demonstration actions	1	0-3
	Catalyst materials	higher conversion rates, better long-term stability	Applied R&D (Programme) Pilot actions	1	0-3
	Fluidized bed materials	high performance, abrasion resistance, high heat transfer	Applied R&D (Project) Pilot actions	2	3-6
	Coating as hydrogen diffusion barrier	Reduce diffusion rate	Applied R&D (Project) Demonstration actions	2	3-6
	Insulation materials	Improved resistance to environmental loads	Applied R&D (Project) Demonstration actions	2	3-6
	Transparent receiver cover	Allow for high temperature closed receiver/reactors at 800 °C	Applied R&D (Project) Demonstration actions Pre-normative research	2	3-6
Reflectors	Mirror protective coatings	Improved anti-soiling function	Applied R&D (Programme) Demonstration actions	1	0-3
	Mirror surface degradation for non-glass mirrors	Degradation processes in different climatic conditions and under abrasion, improved accelerated ageing tests	Applied R&D (Programme) Reference test facility and pre-normative research	1	0-3

Priorities for Near/Medium Term Materials Research for CSP Systems					
Component /system	**Materials**	**Aims & Issues**	**Proposed Research Action**	**Priorities (1=high 2=medium 3=low)**	**Time Scale (years)**
			Market measures		
	All mirror technologies	Higher reflectance and/or specularity, cost reduction, sustainability	Applied R&D (Programme) Market measures	1	0-3
	Low-iron glass	Reduced transmission losses; Method for recycling process, Method for treatment of raw materials to reduce the iron content	Applied R&D (Programme)	2	3-6
	Low-lead solutions	Zero lead or minimum lead contents	Applied R&D (Programme)	2	3-6
Support structures	Steels, aluminium, fibre composites	Improved stiffness and stability for larger collector structures; sustainability	Applied R&D (Project) Demonstration actions	3	6-10
		Improved manufacturing processes to lower cost	Applied R&D (Project) Demonstration actions	3	6-10
	Fibre composites	New concepts for low cost and precise components;	Applied R&D (Project) Demonstration actions	3	6-10
Tracking drives	Hardened steels or others	Improved precision, low wear, high reliability in mechanical parts	Applied R&D (Project) Demonstration actions Reference test facility and pre-normative research	3	6-10
Heat exchangers	ceramics or alloys	increase temperatures, reduce cost	Applied R&D (Programme) Pilot actions Demonstration actions	3	6-10
	Structural materials	Decrease cost, optimization for different HTF	Applied R&D (Project) Demonstration actions	3	6-10

6.2. Market Implementation in 2050

Table 2 summarizes the main issues identified for materials research relating to plants expected to come into commercial operation in the period 2030 to 2050.

For all components, basic materials modelling is required for achieve a better understanding of properties and provide as basis for advanced methods to improve performance and for going beyond the current limits (strength, temperature, corrosion resistance, performance etc.)

Table 2 Main issues for materials research and demonstration projects relating to plant designs expected to come into commercial operation in 2050

Component/system	Materials	Aims & Issues	Proposed Research Action
Heat transfer systems	Nanotechnology or other improved fluids	Increase operating temperatures, better heat transfer, better chemical stability	Basic R&D (Programme)
	Multi-scale predictive modelling (molecular dynamics)	Develop capacity to simulate physical heat transfer and storage processes	Basic R&D (Programme)
	New fluids	Allow for heat transfer as well as storage	Basic R&D (Programme)
Heat storage	Solid particles, phase change materials, liquid materials	Thermal properties & reduced costs	Basic R&D (Programme)
	Thermo-chemical energy storage materials	Development of new materials	Basic and applied R&D, demo projects
	Container materials	Development of new cheaper alloys	Basic R&D (Programme)
	Higher temperature storage materials (at least 600 ºC)	Development of new materials, thermal properties, any technology	Basic R&D (Project) Applied R&D (Project) Demonstration projects
Absorbers/ Receivers	Spectrally selective absorber coatings stable both in vacuum and air	Increased absorptance, resistance to higher temperatures (1000°C)	Basic and applied R&D, Demonstration actions
	Alloy/ceramic tubing for super-critical steam cycle	Resistance to temperatures up to 1000°C and to high internal pressures	Basic and applied R&D, Demonstration actions
	Catalyst materials	high performance, better conversation rates, long term stability	Basic R&D (Programme) Applied R&D (Programme) Demonstration actions
	Fluidized bed materials	high performance, abrasion resistance, high heat transfer	Basic R&D (Programme) Applied R&D (Programme)

Component/system	**Materials**	**Aims & Issues**	**Proposed Research Action**
	Ceramics	Increase operation temperature for Brayton cycles and solar fuel production to 1200-1400°C	Basic R&D (Programme) Applied R&D (Programme)
	Transparent receiver cover	For high temperature receivers with actively cooled window for 1200°C or higher	Basic R&D (Programme) Applied R&D (Programme) Demonstration actions
Reflectors	Non-glass reflective surfaces like films, foils, membranes, as a possible alternative to glass mirrors	high resistance to weathering and abrasion, cost reduction	Basic R&D (Programme) Applied R&D (Programme) Demonstration actions Reference test facility and pre-normative research
Structures	Steel, aluminium and fibre composites	Increase aperture area to 150%	Applied R&D (Project) Demonstration actions

7. REFERENCES

ESTELA and AT Kearney, June 2010. Solar Termal Electricity 2025. Available online on http://www.estelasolar.eu/fileadmin/ESTELAdocs/documents/Cost_Roadmap/2010-06%20-%20Solar%20Thermal%20Electricity%202025%20-%20ENG.pdf

Amsbeck, Lars und Denk, Thorsten und Ebert, Miriam und Gertig, Christian und Heller, Peter und Herrman, Patrik und Jedamski, Jens und John, Joachim und Tobias, Prosine•ki und Rehn, Johnny (2010) Test of a Solar-Hybrid Microturbine System and Evaluation of Storage Deployment, Solarpaces 2010, 21.-24.Sept. 2010, Perpignan, France

Heller, Peter und Pfänder, Markus und Denk, Thorsten und Tellez, Felix und Valverde, Antonio und Fernández, Jesús und Ring, Arik (2006) Test and evaluation of a solar gas turbine system, Solar Energy, 80 (10), Pages 1225-1230

Sugarmen C., Ring A., Buck R., Heller P., Schwarzbözl P., Téllez F., Marcos M. J. and Enrile J. (2003): Solar-Hybrid Gas Turbine Power Plants – Test Results and Market Perspektives. Proc. ISES Solar World Congress 2003, June 14-19, 2003, Göteborg, Sweden.

Cabeza, L.F., A. Castell, C. Barreneche, A. de Gracia, A. I. Fernández, 2011: Materials used as PCM in thermal energy storage in buildings: A review. Renewable & Sustainable Energy Reviews, 94(10), 1723-1729.

Foster, M., 2002: Theoretical investigation of the system SnO_x/Sn for the thermochemical storage of solar energy, Proc. 11th SolarPACES Int. Symp. on Concentrating Solar Power and Chemical Energy Technologies, Zürich, Switzerland.

Helm, M., C. Keil, S. Hiebler, H. Mehling, C. Schweigler, 2009: Solar heating and cooling system with absorption chiller and low temperature latent heat storage: Energetic performance and operational experience. International Journal of Refrigeration, 32(4), pp. 596-606.

Kenisarin, M.M., 2010: High-temperature phase change materials for thermal energy storage. Renewable & Sustainable Energy Reviews, 12, pp. 955-970.

Kearney, D., U. Herrmann, P. Nava, et al., 2006: Assessment of a molten salt heat transfer fluid in a parabolic trough solar field. Journal of Solar Energy Engineering-Transactions of the ASME, 125, pp.170-176.

Lovegrove, K., A. Luzzi, and H. Kreetz, 1999. A solar-driven ammonia-based thermochemical energy storage system. Solar Energy, 67, pp. 309-316.

Nomura, T., N. Okinaka, and T. Akiyama, 2010: Technology of latent heat storage for high temperature application: a review. ISIJ International, 50, pp. 1229-1239.

Pilkington Solar International GmbH, 2000: Survey of thermal storage for parabolic trough power plants. National Renewable Energy Laboratory SR-550-27925.

Sena-Henderson, L. 2006: Advantages of using molten salts, national solar thermal test facilities. SANDIA Laboratories Internal Report.

Steinfeld, A., and A. Meier, 2004: Solar Fuels and Materials. In: Encyclopedia of Energy. Elsevier, Amsterdam, The Netherlands, pp. 623-637.

Tamme, R., 2003. Concrete storage: Update on the German concrete TES program. Presented at the Workshop on Thermal Storage for Trough Power Systems; Institute of Technical Thermodynamics.

Van Berkel, J., 2005: Storage of Solar Energy in Chemical Reactions. In Thermal Energy Storage for Solar and Low Energy Buildings, Jean-Christophe Hadorn, Ed. Lleida Spain: Servei de Publicacions de la Universitat de Lleida.

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Abstract
Experts from European research orgnaisations and industry have assessed the state of the art and future needs for materials' R&D for concentrating solar power technologies. The work was performed as input to the European Commission's roadmapping exercise on materials for the European Strategic Energy Technology Plan. The report summarises the results, including the priorities identified for the medium (2020/2030) and long (2050) term.

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