European Commission

LOW CARBON ENERGY OBSERVATORY

SOLAR THERMAL ELECTRICITY
Technology development report

Joint Research Centre

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FOREWORD ON THE LOW CARBON ENERGY OBSERVATORY

The LCEO is an internal European Commission Administrative Arrangement being executed by the Joint Research Centre for Directorate General Research and Innovation. It aims to provide top-class data, analysis and intelligence on developments in low carbon energy supply technologies. Its reports give a neutral assessment on the state of the art, identification of development trends and market barriers, as well as best practices regarding use private and public funds and policy measures. The LCEO started in April 2015 and runs to 2020.

Which technologies are covered?

- Wind energy
- Photovoltaics
- Solar thermal electricity
- Solar thermal heating and cooling
- Ocean energy
- Geothermal energy
- Hydropower
- Heat and power from biomass
- Carbon capture, utilisation and storage
- Sustainable advanced biofuels
- Battery storage
- Advanced alternative fuels

How is the analysis done?

JRC experts use a broad range of sources to ensure a robust analysis. This includes data and results from EU-funded projects, from selected international, national and regional projects and from patents filings. External experts may also be contacted on specific topics. The project also uses the JRC-EU-TIMES energy system model to explore the impact of technology and market developments on future scenarios up to 2050.

What are the main outputs?

The project produces the following report series:

- Technology Development Reports for each technology sector
- Technology Market Reports for each technology sector
- Future and Emerging Technology Reports (as well as the FET Database).

How to access the reports

Commission staff can access all the internal LCEO reports on the Connected LCEO page. Public reports are available from the Publications Office, the EU Science Hub and the SETIS website.

ABBREVIATIONS AND DEFINITIONS

CPC	common patent
CSP	Concentrated Solar [thermal] Power
CR(S)	central receiver (system), aka solar tower system
EPC	engineering, procurement and construction
ETS	Emission Trading System
FiT	feed-in tariff
FOAK	First–of-a-Kind
GW	Giga Watt
HTF	heat transfer fluid
IA	Innovation Action
IEA	International Energy Agency
ISCC	integrated solar combined cycle
IP	Implementation Plan
LCoE	levelised cost of electricity
MENA	Middle East and North Africa
MSCA	Marie Skłodowska-Curie Action
PPA	power purchase agreement
PV	photovoltaic
RES	Renewable Energy Source
RIA	Research and Innovation Action
SET	Strategic Energy Technology
STE	solar thermal electricity
TES	thermal energy storage
TRL	Technology Readiness Level

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1 INTRODUCTION

Solar thermal electric plants[1] generate electricity by converting concentrated solar energy to heat, which is in turn converted to electricity in a thermal power block. Combined with a thermal energy storage system it provides dispatchable renewable electricity. This can help achieve the EU's energy transition [1], support EU jobs and economic growth, and contribute to meeting the commitments made in the 2015 COP-21 Paris Agreement [2].

This LCEO Technology Development Report aims to provide an unbiased assessment of development trends, targets and needs, of technological barriers and of techno-economic projections until 2050. Particular attention is paid to how EC funded projects contributed to technology advancements. It follows the structure and methodology set out in the updated LCEO Work Programme (as revised in 2017). A companion LCEO Technology Market Report will cover recent developments (from 2010 onwards) and medium and long-term perspectives for CSP technology markets, highlighting the role of EU stakeholders.

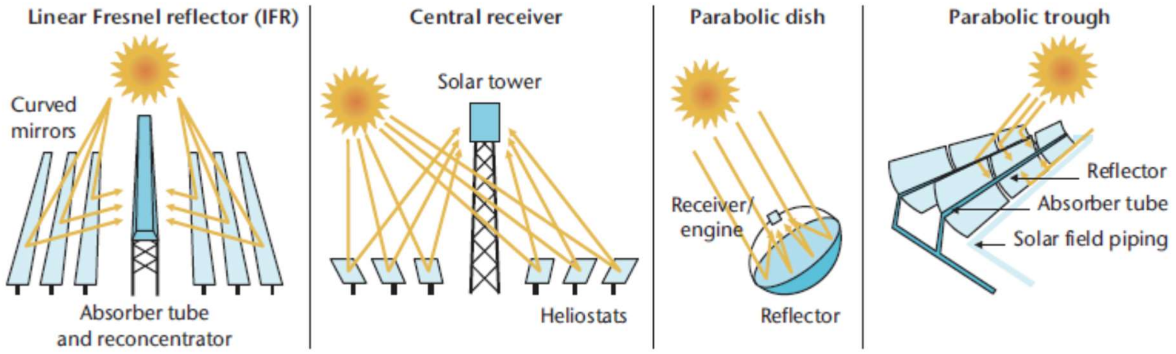
1.1 Main Characteristics of the Technology

Figure 1 shows a schematic of the main design concepts. The two major designs used today are p*arabolic trough* power plants and central receiver or p*ower tower systems*. Both can include a heat storage system, which allows electricity generation in the evening and night. Systems with linear Fresnel receivers (essentially a variation on the power trough concept, but using flat mirror elements to concentrate the light) are also in commercial operation. The parabolic dish with a Stirling engine receiver is researched as well, but there are no plants in commercial operation.

STE systems comprise the following main elements:
- solar field
- receiver and heat transfer system
- thermal storage system
- power conversion unit (heat to electricity) and balance of plant.

In terms of capital costs, the solar field is presently the largest single element, accounting for about 40% of the total. STE plants are rated in terms of the maximum rated power output in MW (AC electricity output). The annual load capacity factor for commercial plants is approximately 27% i.e. 2 300 to 2 400 MWh/yr/MW.

Figure 1 Main solar thermal electricity generation concepts: most current CSP plants are based on trough technology, but tower technology is increasing and linear Fresnel installations emerging. No parabolic dish systems are in commercial operation



(source IEA [3])

[1] In this report the term solar thermal electricity (STE) is used interchangeably with concentrated solar power (CSP). In principle STE also includes non-concentrating solar technologies, of which the solar chimney (solar updraft tower) is the main example. However this is not addressed here.

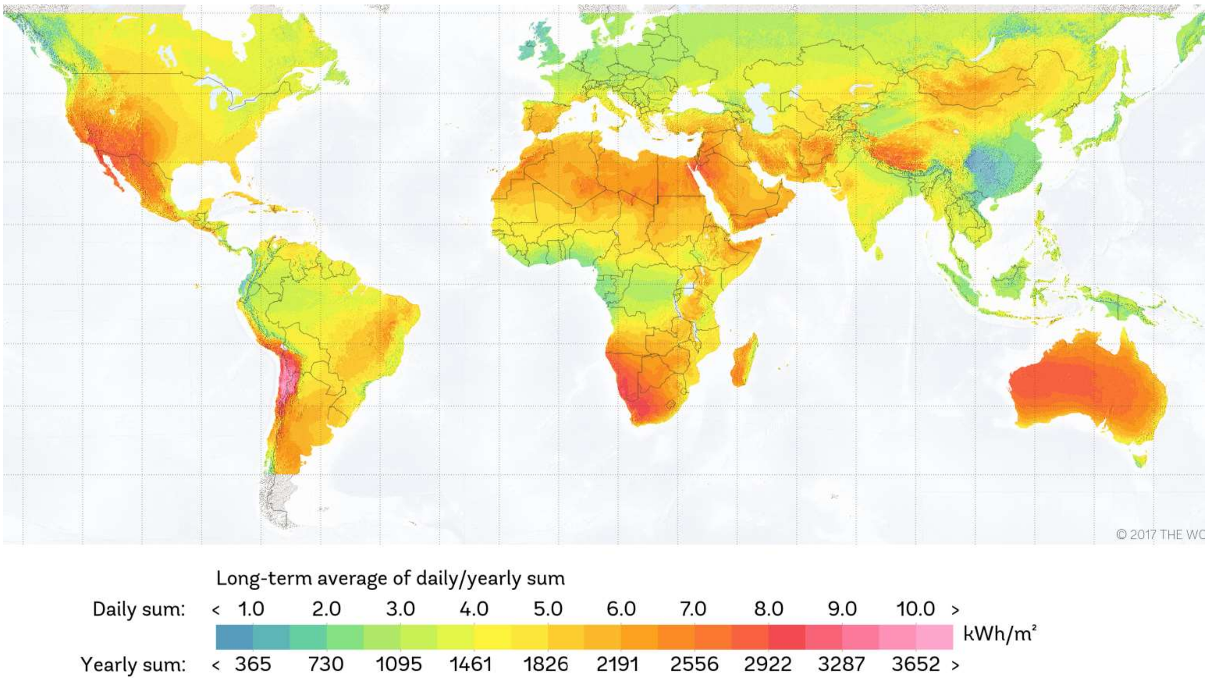
STE plants require high levels of steady, direct normal insolation (DNI > 2000 kWh/m^2/year). This limits the range of potential locations in the first instance, as shown in Figure 2. Only southernmost Europe offers suitable (but not good) locations. Applying further site exclusion criteria such as land slope > 2.1 % and land cover such as permanent or non-permanent water, forests, swamps, agricultural areas, shifting sands, salt pans, settlements, oil or gas fields, mines, etc., leads to an even more restricted range of potential locations [4]. On the other hand, the available resource is still enormous and points to the possibility for export of electricity from areas with high resource to areas with high electricity demand. For instance, the Desertec proposal some years ago envisaged high capacity connectors from MENA countries to the EU.

STE can also be combined with other power generation technologies, either for solar-assisted power generation (where the solar heat is used to boost performance of a high-availability fossil plant) or in hybrid configurations (where the STE plant is supported by other sources, for instance biogas, geothermal heat sources or PV)[2].

Although this report is focusses on electric power generation (STE plants), concentrated solar systems may also be used to provide heat for enhanced oil recovery or industrial processes. Fuel synthesis is a future option, as demonstrated by EU supported projects[3] on the feasibility of using concentrated solar radiation for thermochemical splitting of H_2O and CO_2 into hydrogen and carbon monoxide (syngas), the precursor to kerosene and other liquid fuels.

Finally, an aspect of potential strategic importance is that the locations most favourable for STE are also amongst those for which water supply is either already a major issue or at risk in the future. This points to a role for STE combined with water desalination, although a broad range of cost and environmental factors need to be taken into account [5].

Figure 2 Map of direct normal solar irradiation: a level of 2000 kWh/m^2 or is considered necessary for solar thermal power generation (effectively the orange/red areas) © 2017 The World Bank, Solar resource data: Solargis



[2] In general STE plants include an additional fossil heat source to support the heat transfer and thermal storage circuits overnight or in periods when there is a lack of solar heat.

[3] See the sites for the FP7 SOLAR-JET Project and its H2020 follow-up SUN-to-LIQUID.

1.2 Market Status

The development of the sector has been somewhat discontinuous. In the mid-2000s, after a gap of more than 15 years, the first new major STE capacities plants came online with Nevada One (64 MW , USA) and the PS 10 plant (11 MW, Spain) in the first half of 2007. In Spain approximately 45 plants of 50 MW size were installed in the period 2009-2013. However in 2012 a change in Spanish government policy effectively halted further developments in that country. The current phase is truly international, with new plants in the USA, Morocco, Chile, South Africa and China. It has also seen a move to larger plants, >100 MW, which can bring economies of scale and reduced capital costs.

The market is still dominated by the parabolic trough technology, which is used by more than 80% of the CSP power plants in operation or under construction. In 2017, global installed capacity of STE reached approximately 5.13 GW, with an increase of 2.2% over 2016[4]. In June 2018, China's first commercial-scale STE project, the China Guangdong Nuclear Power Delingha 50MW parabolic trough station, was connected to the grid[5]. Overall however STE remains for now well behind the major renewable technologies such as wind, photovoltaics and bioenergy.

In the EU, current installed capacity is 2.4 GW, but growth is stalled. Projections for 2030 are for modest growth – for instance the 2018 IRENA REMap analysis [6] includes 6 GW of CSP by 2030 in the EU, as part of a 34% renewables scenario. European industry (51 companies in nine EU countries [7]) remains a leader in this sector, providing technology and operational expertise globally.

1.3 Methodology and data sources

The methodology for the technology development reports is based on three main pillars:

- JRC peer review and expert judgement;
- Monitoring, data compilation; definition and use of indicators, for which the focus is the technology readiness level (TRL) parameter, using the guidelines set out in the 2017 study contract for DG-RTD [8].
- Modelling of long-term deployment trends, using the JRC-EU-TIMES model.

The data sources are divided as follows:

i) R&D projects
ii) Patents statistics, for patents filed on technologies/sub-technologies
iii) Scientific publishing statistics from the JRC's TIM (Tools for Information Monitoring) software
iv) Existing scientific overviews and compilations

[4] http://www.solarpaces.org/csp-capacity-grew-2-5-13-gw-2017/
[5] https://www.solarpaces.org/chinas-first-concentrated-solar-power-csp-has-connected-to-the-grid/

2 STATE OF THE ART

Table 1 sets out the baseline technology characteristics for the STE systems. As mentioned above, parabolic trough designs are the most widely deployed and are considered most bankable for project financing. Nonetheless several recent developments have opted for central receiver designs (also known as or solar towers), which allow a higher maximum temperature and hence increased efficiency for power generation and thermal heat storage. On the other hand they can be more sensitive to site climatic conditions due to attenuation of the light between the mirrors and the receiver.

In terms of technology development, there are a wide range of options for improving the performance and cost effectiveness of STE plants [3, 9, 10, 11]. In 2017 the Solar Energy journal dedicated a special issue to CSP with a series of technology reviews [12]. Gauché et al [13] provided an assessment of issues for future developments at different time scales (**Table 2**)

At EU level, the SET-Plan working group has developed a comprehensive planning for R&D and demonstration activities [14, 15, 16] based around the following two targets:

- Short-term: > 40% cost reduction by 2020 (from 2013) translating into a supply price[6] < 10 c€/kWh for a radiation of 2050 kWh/m^2/year (conditions in Southern Europe)
- Longer-term: develop the next generation of CSP/STE technology: new cycles (including supercritical ones) with a first demonstrator by 2020, with the aim to achieve additional cost reductions and opening new business opportunities.

In particular, the CSP Implementation Plan [16] established a ranking of research and innovation activities, as well as stressing the need for at least three first–of-a-kind (FOAK) commercial-scale plants to be developed in Europe. Table 3 lists these activities together with envisaged the TRL increase in the medium term (to 2025).

Table 1 Main characteristics of state-of-the-art commercial parabolic trough (PT) and central receiver (CR) plants (source: 2015 KIC InnoEnergy report [9] and other as indicated).

	Parabolic Trough	**Central Receiver**
Receiver	Line absorbers with high absorptivity (>95%) and low emissivity (<10%);	Metallic point receivers
Heat Transfer Fluid	Thermal oil at max. 395 ºC	Molten salt or steam; max. working fluid temperatures of 570 ºC
Thermal energy storage	Two-tank molten salt	
Power cycle	Rankine with superheated steam (ORC for smaller facilities)	Rankine with superheated steam
Capacity factor[7] (2050 DNI location)	27%, or greater with TES	26%, or greater with TES
Land area required	2.4 – 3.2 hectares/MW (direct area, including TES)	
Water consumption	3.5 m^3/MWh (with wet cooling[8], as for fossil plants)	
CO2 footprint	22 gCO/kW h [17]	

[6] The targeted price for 25-year power purchase agreements

[7] Since the nominal power output of the generator in a CSP plant is fixed, the capacity factor can be increased by increasing the size of the solar field and adding a thermal storage system, so the power generator can run after sundown; values up to 60% are proposed.

[8] Dry cooling designs can reportedly reduce the water consumption by 90%, but with a 10% cost penalty on the electricity generated due to the higher plant costs and reduced cycle efficiency.

Table 2: from P. Gauche' et al – "Near, mid and long term CSP commercialisation map" [13]

Technology area	Near-term (5 year)	Mid-term (5–15 years)	Long-term (15–30 years)
Reflector materials	• Lower lifecycle cost for solar mirrors	• Advanced solar mirrors • Reflector film	• Smart reflector surfaces
Concentrators	• Wireless heliostats • Increase use of sensors and autonomy • Very low cost parabolic trough for molten salt • Modular CSP units	• Resurgence of Linear Fresnel and/or Linear mirrors • Autonomy for most services • Beam down towers	• Micro paraboloid (dish) • Lifecycle autonomy
Receivers	• Selective coatings • Air receivers • Improved experience	• Particle receivers	• Receivers for micro paraboloid concentrators
Storage	• Advanced molten salt • Thermoclines • Concrete (lower temperature) • Target 10+ hours of storage	• Particle storage • Lower cost thermoclines • Initial thermo-chemical • Thermal storage graduates from CSP as renewable system balancing technology • Target 15 h storage	• Thermo-chemical for seasonal storage (fuels) • Target: Transportable fuels enable crossing the diurnal (24 h) cycle
HTF	• Advanced molten salt • Early potential for Sodium and air	• Liquid metals • Particles • Air	
Working fluids	• Air	• Supercritical CO_2	• Some abandonment from direct CSP
Generators	• CSP optimized steam generators for daily thermal cycling, which requires different thinking to conventional power generation	• Breyton and combined cycle • Supercritical CO_2	• "Solid state" (thermoelectric, thermovoltaic, CPV with storage) • Separation from CSP with generation from solar thermal generated fuels
Water consumption	• Improved and optimized dry and hybrid cooling	• Completely "dry" cycles and water reduction for mirror washing	• Continued improvements in reflector washing

Table 3 SET-Plan CSP Implementation Plan - Ranking of R&I Activities and expected improvement of TRL.

Priority	Proposed Activity	Targeted TRL Change by 2025
1	Improved central receiver molten salt technology	7→9
2	Parabolic trough with silicon oil (target 430 °C working temperature)	6→8
3	Next generation of central receiver power plants	6→8
4	Advanced Fresnel technology with direct molten salt circulation for HTF and TES	6→8
5	Parabolic trough with molten salt	6→8
6	Scale-up of open volumetric air receiver technology	6→8
7	Multi-tower central receiver beam down system	5→7/8
8	Thermal energy storage	4→7
9	Supercritical steam turbines for CSP	
	State-of-art max. temperatures	→7
	Max. Temperature > 650 °C	5→7
10	Advanced concepts for improved flexibility in CSP applications	
	Topic 1 improved steam turbine operation	→3
	Topic 2 Development of CSP plan analytics	3→6
11	Development and field test of CSP hybrid air Brayton turbine combined cycle sCO2 systems	3→6
12	Pressurized air cycles for high efficiency solar thermal power plants	5→7

2.1 Global and European Trends

2.1.1 Scientific Publications

The JRC Technology innovation Monitoring tool (TIM[9]) provides the functionality to analyse scientific publications in its database, which contains documents from Scopus (Elsevier) published after 1996. **Figure 3** shows the geographical breakdown of the CSP data for 2016[10]. The data underlines the leading role of Europe and the USA in R&D for STE and CSP technologies. Indeed European organisations were involved in almost 50% of scientific publications in this field. The significant presence of Chinese organisations can also be seen.

Figure 4 looks at the inter-organisation links as evidenced by joint shared publications. The main clusters and participants emerge as follows:

- Abengoa - U. Lleida – Tecnalia – U. Barcelona + others
- CIEMAT – DLR, focussed around the Plataforma Solar de Almería[11], the largest concentrating solar technology research, development and test centre in the world.
- NREL + others (USA)
- CNRS – U. Perpignan
- U. Seville – CENER – Abengoa + others
- UPM + others

There are also links between the clusters, and indeed European organisations have collaborated intensively over the last 20 years, aided by support from EU projects such as SFERA-I and SFERA-II and most recently the EU-SOLARIS Research Infrastructure initiative. EU-SOLARIS aims to provide the most complete, high quality scientific infrastructure portfolio at international level and to facilitate access to it.

Lastly **Figure 5** looks at clustering of keywords in the 2016 CSP related publications. There is broad coverage of the technology sub-topics, but the large research effort on thermal transfer and storage issues is evident

Figure 3 Global distribution of authors of CSP research publications in 2016 as extracted by TIM from the SciVerse Scopus database. European authors and organisations are involved in almost half of all publications.

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[9] EU, Joint Research Centre, Tools for Innovation Monitoring, http://www.timanalytics.eu/

[10] TIM search command: ti_abs_key:("concentrated solar power" OR "solar thermal electricity") AND emm_year:2016 AND class:(article OR conf OR review OR boch)

[11] PSA is located in south-eastern Spain, in the Tabernas Desert. It receives a direct annual insolation of more than 1900 kWh/(m2•year) and the average annual temperature is around 17ºC. It has over 30 years of experience in the operation, maintenance and evaluation of solar thermal concentrating systems.

Figure 4 TIM tool analysis of the clustering of organisations involved in scientific publications in 2016 on CSP.

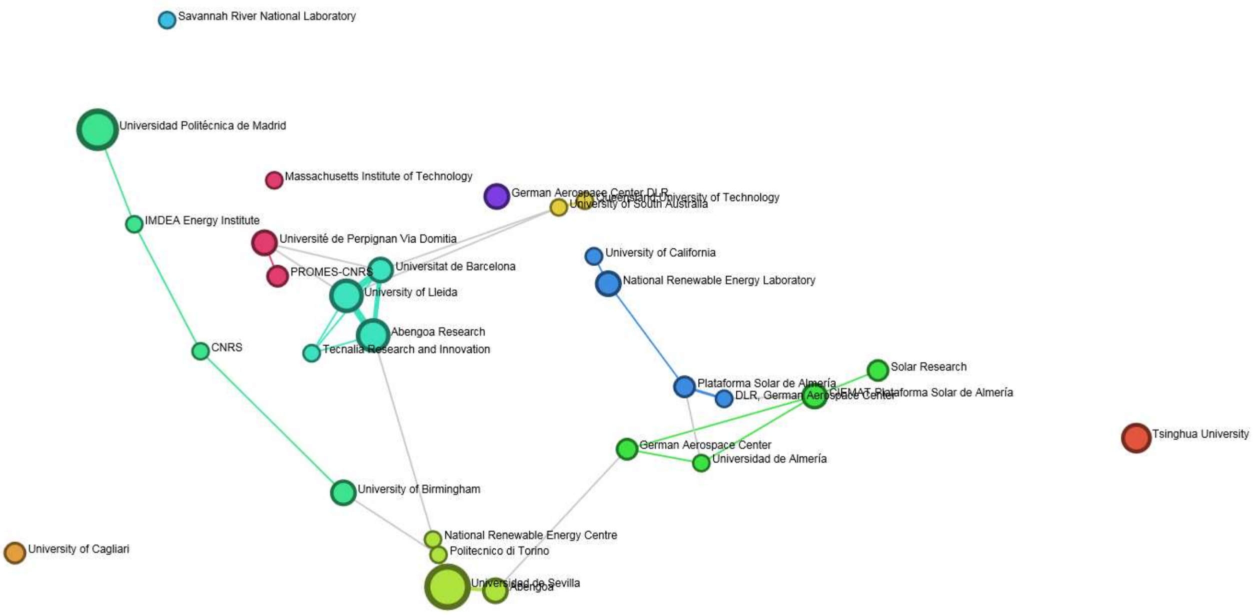
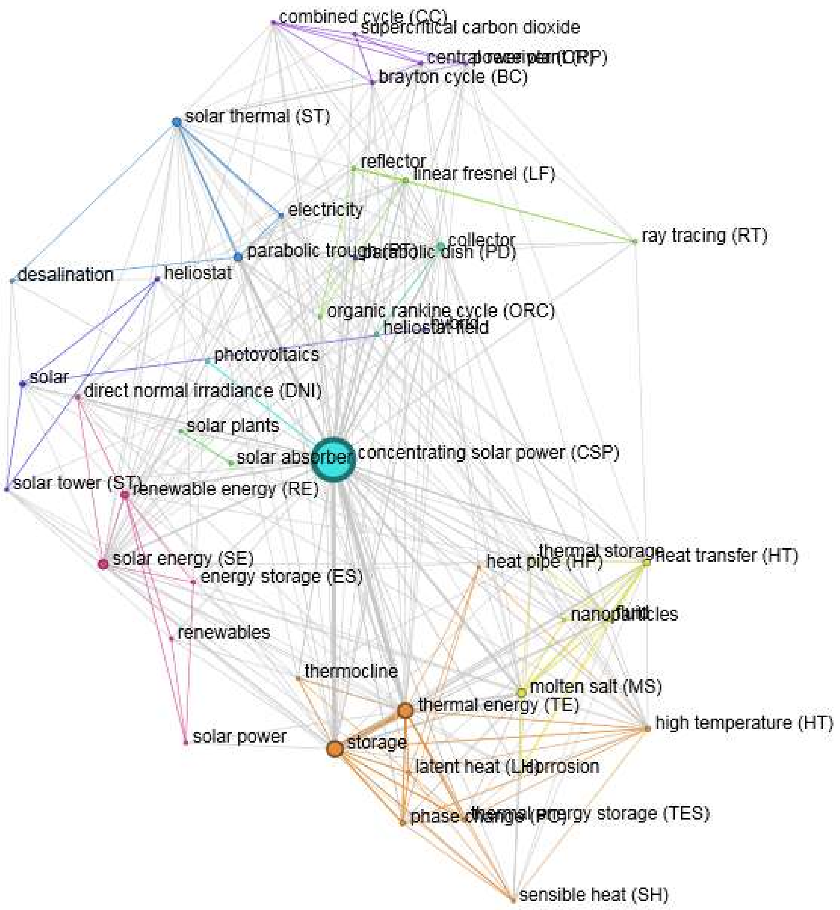


Figure 5 TIM tool analysis of the clustering of CSP sub-topics in scientific publications in 2016.



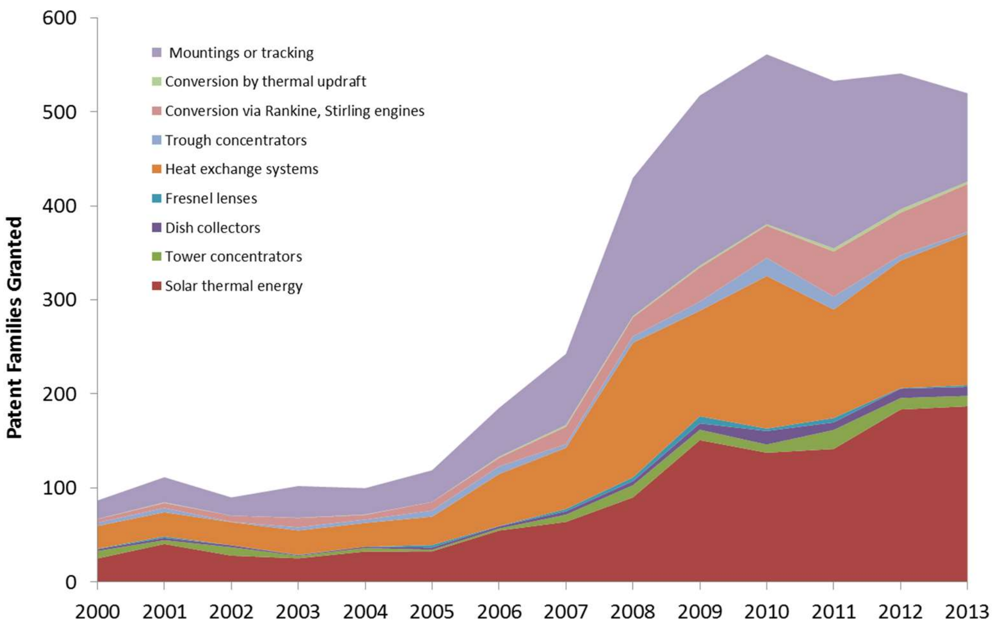
2.1.2 Patents

This analysis looked at the Patstat (European Patent Office) data for the period to 2013[12]. The CPC codes relevant to CSP are as follows:
Y02E 10/40 - Solar thermal energy
Y02E 10/41 - Tower concentrators
Y02E 10/42 - Dish collectors
Y02E 10/43 - Fresnel lenses
Y02E 10/44 - Heat exchange systems
Y02E 10/45 - Trough concentrators
Y02E 10/46 - Conversion of thermal power into mechanical power, e.g. Rankine, Stirling solar thermal engines
Y02E 10/465 - Conversion of thermal power into mechanical power, thermal updraft
Y02E 10/47 - Mountings or tracking

Figure 6 shows the trend in counts of patent families[13] per year. Overall filings grew strongly from 2000 up to 2010, and then stabilised and even slightly decreased from 2011 to 2013. The main application areas were for the generic solar thermal energy category (Y02E 10/40)[14], for heat exchange systems (Y02E 10/44) and for mounting and tracking (Y02E 10/44). YE02 10/46 for innovations in Rankine and Stirling solar thermal engines also grew strongly. The overall volume of patents (>3 000) precludes a detailed analysis of content.

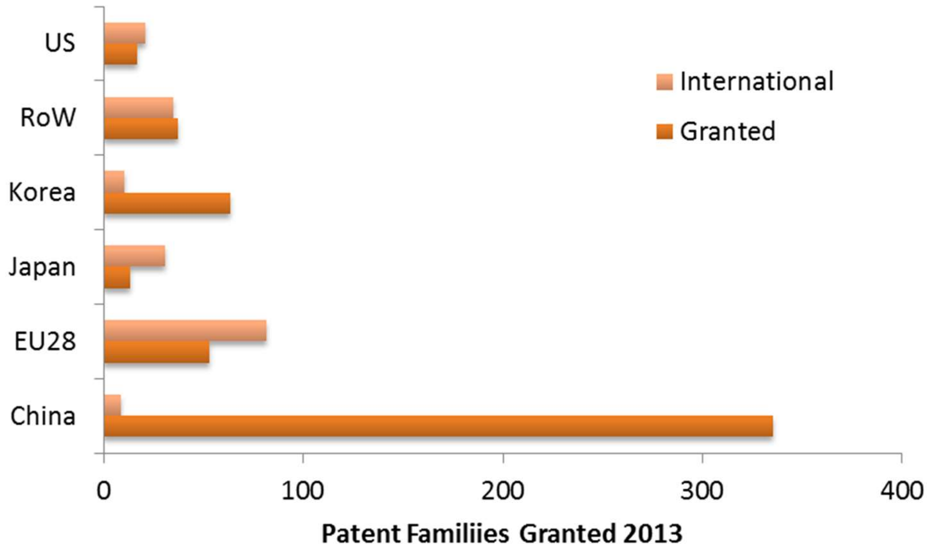
Figure 7 shows the global regional breakdown for 2013, considering both all patents granted and those with international[15] recognition. For the former, China was far ahead of the other regions, with over 50% of patents granted. Those with international recognition make up approximately one third of the total, but here the regional breakdown is very different. The EU is leader, accounting for 38%, followed by the rest of the world with 18% and then Japan with 16%.

Figure 6 Global trends in patenting under the main CSP application groups for 2000-2013.



[12] There is a time lag of 4 years to obtain complete data for a given year.
[13] Patent documents are grouped in families, under the assumption that one family equals one invention.
[14] Regarding the high proportion of patents under the generic solar thermal codes, it seems that detailed codes (subcategories) are only given when the examiners (or the algorithms they use) are completely certain that a patent application strictly relates to that specific application area, otherwise it goes in the general basket.
[15] International indicates that a patent family includes patent applications filed in more than one patent office; such patent families can also be termed "high-value", as it implies that the applicant foresees wide uptake.

Figure 7 Regional breakdown of patent families for 2013, showing those granted and those also flagged international.



2.2 EU programmes

2.2.1 Horizon 2020

Based on data for the period 2014-2017, the EU has supported 26 CSP/STE projects with approximately EUR 89m contribution (and a total budget in excess of EUR 100m).

Table 4 shows a summary listing of these projects, with a breakdown into the different programmes types. The majority of the projects (87% by funding) are R&D activities (IAs and RIAs), with one FTIPilot project (3% of funding). A comprehensive list is provided in Annex 1 with details on the technical objectives, targeted TRL and progress to date (Chapter 4 considers the technical focus in more detail).

2.2.2 Smart Specialisation

Smart specialisation is an innovative approach that aims to boost growth and jobs in Europe, by enabling each region to identify and develop its own competitive advantages. The interregional partnership for solar energy and smart specialisation has been running since 2015 and is currently working on 4 different projects/concepts:

- FOAK project: CSP plant hybridised with PV, including storage to provide fully dispatchable power and to allow for more flexible generation;
- Research facility for solar technologies;
- Promotion of electricity exports from solar technologies from Southern to Central and Northern European countries;
- Use of medium temperature solar energy in the agro industry.

2.2.3 NER 300

The aim of NER 300[16] is to establish a demonstration programme of CCS and RES projects involving the EU Member States. Table 5 shows the current status for CSP-related projects, which in general have struggled to find full funding (the NER 300 award covers only a percentage of the total costs).

[16] NER300 is a financing instrument managed jointly by the European Commission, the European Investment Bank and the EU Member States, that uses 300 million ETS allowances (rights to emit 1 t CO_2) in a new entrants' reserve for subsidising installations of innovative renewable energy technology and carbon capture and storage. For the period 2021-2030 the Commission has proposed a new programme called Innovation Fund.

Table 4 Horizon 2020 CSP projects

Project Acronym	Project Title	Project Type	EC Contribution EUR
MSLOOP 2.0	Molten Salt Loop 2.0: key element for the new solar thermal energy plants	FTIPilot	2,436,373
IN-POWER	Advanced Materials technologies to quadruple the Concentrated Solar Thermal current power generation	IA	4,998,928
ORC-PLUS	Organic Rankine Cycle - Prototype Link to Unit Storage	IA	6,249,316
PreFlexMS	Predictable Flexible Molten Salts Solar Power Plant	IA	14,362,194
RAISELIFE	Raising the Lifetime of Functional Materials for Concentrated Solar Power Technology	IA	9,291,723
NEXTOWER	Advanced materials solutions for next generation high efficiency concentrated solar power (CSP) tower systems	IA	4,999,778
CAPTure	Competitive SolAr Power Towers – CAPTure	RIA	6,104,033
MinWaterCSP	Minimized water consumption in CSP plants	RIA	5,861,372
MOSAIC	MOdular high concentration SolAr Configuration	RIA	5,077,734
NEXT-CSP	High Temparature concentrated solar thermal power plant with particle receiver and direct thermal storage	RIA	4,947,420
SOCRATCES	SOlar Calcium-looping integRAtion for Thermo-Chemical Energy Storage	RIA	4,994,153
SOLPART	High Temperature Solar-Heated Reactors for Industrial Production of Reactive Particles	RIA	4,366,563
WASCOP	Water Saving for Solar Concentrated Power	RIA	5,941,608
CySTEM	Cyprus Solar Thermal Energy Chair for the Eastern Mediterranean	CSA	2,500,000
MUSTEC	Market uptake of Solar Thermal Electricity through Cooperation	CSA	2,396,526
NESTER	Networking for Excellence in Solar Thermal Energy Research	CSA	1,060,798
DIMONTEMP	Distributed Monitoring of HTF Temperature at Solar Thermal Power Plants	SME instrument	50,000
HELIOtube	Inflatable solar collectors for a low cost CSP Plant with irreducibly small carbon footprint	SME instrument	1,843,052
HELITE	High precision and performance heliostat for variable geometry fields of Thermosolar Plants	SME instrument	50,000
TENCENT	The next generation of Hybrid Concentrating Solar Power Plants	SME instrument	50,000
TRANSREGEN	Portable thermal fluid regeneration system for Solar Thermal Plants	SME instrument	50,000
FRIENDS2	Framework of Innovation for Engineering of New Durable Solar Surfaces	MSCA	454,500
GLASUNTES	Innovative high temperature thermal energy storage concept for CSP plants exceeding 50% efficiency	MSCA	259,558
NPMSSES	Nanoparticle Enhanced Molten Salts for Solar Energy Storage	MSCA	195,455
SESPer	Solar Energy Storage PERovskites	MSCA	239,191
THERMOSTALL	High Performance Seasonal Solar Energy Latent Heat Thermal Storage Using Low Grade, Low Melting Temperature Metallic Alloys	MSCA	195,455

Table 5 NER-300 projects for CSP

Project/Plant	Country	Technology	Budget m€	Status (extracted from NER 300 website)
HELIOS POWER	Cyprus	Stirling dish	46,6	"Financing finalization and the initiation of the construction phase." [JRC Note. The project shall enter into operation by end of 2018.]
MAXIMUS	Greece	Stirling dish	44,6	"Complete signing of Power Purchase Agreement, Connection Agreement, legally binding Instrument and financing closure, in order to proceed to the project construction commencement within 2017."
MINOS	Greece	Solar tower	42,1	"Complete financing"
PTC50-ALVARADO	Spain	Solar tower	70,0	Cancelled
EOS GREEN ENERGY	Cyprus	Solar tower	60,2	June 2018: "No legally binding instrument has been signed; terms to be finalised with EPC contractor up to 30 June 2017"; "Solastor Pty Ltd from Australia will supervise production and assembly of the equipment." [JRC Note. Part of equipment from China]
MAZARA SOLAR	Italy	Solar tower	40,0	"Under preparation"

2.3 Other R&D Programmes

2.3.1 SET Plan Countries

The SET-Plan CSP Implementation Plan outlines the main national activities in each of the priority areas. Countries with significant efforts on CSP R&D include Spain, Germany, France, Cyprus, Portugal, Italy and Belgium. These countries also work together in the SOLAR-ERA.NET network[17], which up to now has funded five CSP projects [18], as shown in **Table 6**. This represents a total financing of approximately EUR 6.7 million, of which well over half comes from public funding. Up to now there has been no detailed information on the results obtained.

2.3.1 SolarPACES

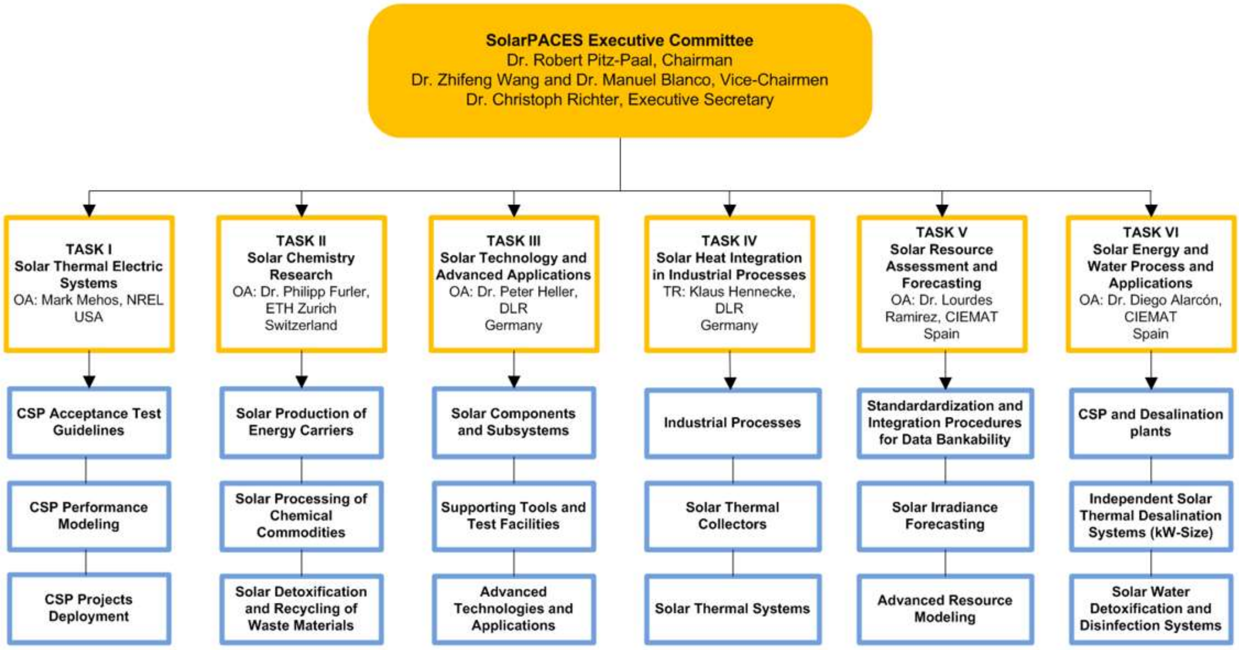
The IEA oversees a technology collaboration programme for Solar Power and Chemical Energy Systems called SolarPACES. It reports to the Working Party on Renewable Energy Technologies (REWP). Currently SolarPACES has 19 members: Australia, Austria, Brazil, Chile, China, European Commission, France, Germany, Greece, Israel, Italy, Mexico, Morocco, Republic of Korea, South Africa, Spain, Switzerland, UAE and USA. **Figure 8** shows the task structure and task leaders. European organisations play a very prominent role, providing the chair and five Operative Agents.

[17] SOLAR-ERA.NET brings together more than 20 European RTD and innovation programmes in the field of solar electricity technologies (PV and CSP). It is co-funded by the EU Framework Programme. As part of the SET-Plan, it aims to: initiate / support innovative, industry-led projects, improve cooperation between RDI programmes and strengthen Europe's position in the solar sector.

Table 6 CSP projects funded under the SOLAR-ERA.NET calls to date

No.	Acronym	Title	End Date	Project Costs EUR	Comment/Status
1	SLAGSTOCK	Low-Cost Sustainable Thermal Energy Storage Systems Made of Recycled Steel Industry Waste	30/04/2018	1 273 286	Completed?
108	EDITOR	Evaluation of the Dispatchability of a Parabolic Trough Collector System with Concrete Storage	31/12/2018	946 802	Running
138	SolFieOpt	Optimal Heliostat Fields for Solar Tower Power Plants	30/09/2019	556 872	Running
123	SITEF[18]	Silicon Fluid Test Facility	31/12/2017	1 395 045	Completed
431	SIMON	Silicon fluid maintenance and operation	31/10/2019	2 500 314	Running

Figure 8 Current structure of the IEA technology collaboration programme for Solar Power and Chemical Energy Systems (SolarPACES)



[18] Both the SITEF and SIMON projects are performed at the PROMETEO test facility of the Plataforma Solar de Almería.

2.3.3 USA

The US Department of Energy Solar Energy Technologies Office runs the Sunshot programme with the overall goal of making solar energy affordable. The new 2030 targets[19] recognise two distinct roles for CSP plants in the electricity market:

- $0.10 /kWh for peaker plants with no more than six hours of energy storage
- $0.05 /kWh for baseload plants with a minimum of 12 hours of energy storage

This reflects interest in the future US power market for peaking plants, in particular in view of the high daily power ramp as PV comes off-line and the evening load increases rapidly. This need could be addressed by modular, smaller (10-50 MW) CSP units with construction time < 1 year.

For central receiver/power-tower technology, DOE has identified the sCO2 cycle as a likely successor to the current steam Rankine cycle due to its potential for high efficiency [19]. In 2018 DOE announced $72 million in funding for three technology pathways, as shown in **Table 7**. After the initial phase, one pathway will be developed as a full-scale test facility (1-10 MWth) coupled to a sCO2 power block operating at 700°C-750°C. This is intended to achieve a 10% efficiency gain and lead to a 20%-30% drop in LCoE.

Table 7 Heat exchange media for high temperature (> 700 ^{o}C) STE cycles.

Pathway	Advantage	Disadvantage
Solid: sand-like particles	experimental particle receivers can operate up to 1,000°C	Particles must be circulated mechanically
New molten salts	Familiarity	Corrosion
Supercritical CO2	Easy to move the sCO2 gas/liquid	Hard to capture and store

2.3.4 China

In 2009 the Ministries of Science and Technology (MOST), of Finance and of Education, the State-owned Assets Supervision and Administration Commission of the State Council, the All China Federation of Trade Unions and China Development Bank established the Chinese National Solar Thermal Energy Alliance as a non-profit membership organisation. Its aim is to lead R&D innovation and promote the solar thermal development and application under the guidance of MOST. As of May 2017, the alliance had 73 members of which 52 were corporations. The members' products and services cover ultra-white glass, parabolic trough concentrators, heliostats, evacuated tube receivers, tracking drivers, tracking controlling systems and molten salts as well as overall system integration and plant engineering construction.

The domestic production base of key equipment for CSP plants in China is still weak, but gradually improving.

With the support of the National High Technology Research and Development Programme (known as 863), the Institute of Electrical Engineering of the Chinese Academy of Science has developed a research project with 9000 m^2 of parabolic trough collectors.

A total CSP installed capacity of 1,35 GW is set out in China's 1st round of demonstration projects, for a FiT of 1.15 RMB/kWh (approximately 0.17 EUR/kWh). The 2020 target is for 5 GW.

In June 2018 China's first large-scale commercial project CGN Delingha (a 50MW parabolic trough plant with 8 hours TES) was connected to the grid.

[19] https://www.energy.gov/sites/prod/files/2018/05/f51/SunShot%202030%20Fact%20Sheet.pdf

3 IMPACT OF R&D WITH EU CO-FUNDING

A listing of projects that have received H2020 funding is presented in Annex 1, based on information from CORDIS[20] and other sources available in September 2018. An estimate of initial and final (or target) TRL is given as one measure of the impact of the work. At this point, all these projects are still running (and indeed many are still at an early stage), so explicit impact assessment is not possible.

In relation to the objectives of the SET-Plan, the following general observations are made (see also Table 8):

- The 12 R&I Activities of the CSP IP are almost all being supported to a greater or lesser extent, the exceptions being the volumetric air receiver concept and customised turbines for CSP with a supercritical steam power cycle. Several projects address multiple areas, as would be expected for research on horizontal themes..
- The TRL targeted by the projects is generally in the range TRL6 to TRL7. This may reflect various factors: a) the scale of funding available for moving a concept to TRL8[21] requires budgets likely to be of the order of EUR 100 million; b) the SET-Plan timescale is medium term (approximately 2025), so the current projects ending around 2020 may represent a first step, and c) a lack of operational plants that could host trials on innovative concepts.
- There is a major focus on advancing the parabolic trough with molten salt combination, with a large IA project (PreFlexMS) and a FTiPilot project (MSLOOP2.0). The overall EU contribution here amounts to EUR 16.8 million. At the time of writing (end 2018), PreflexMS is suspended, highlighting the difficulty of developing demonstration plants.
- The SET-Plan stresses the need for FOAK plants and the lack of success up to now in realising any of the NER 300 concepts is a cause for concern. Also, some clarification of the strategy and prioritisation would be welcome, in the sense that FOAK plants are being proposed for different and not always compatible purposes: as innovative technology test beds, as feasibility scale-ups and as sources of operational reliability data.

Two areas of research fall somewhat outside the CSP IP:

- The theme of dry-cooling, for which there are two projects
- The SME Instrument project HELIOTUBE represents a significant investment (approximately EUR 2 million) in a system that can be manufactured with roll-to-roll technology

[20] The Community Research and Development Information Service (CORDIS) is the European Commission's primary source of results from the projects funded by the EU's framework programmes for research and innovation (FP1 to Horizon 2020). https://cordis.europa.eu/en

[21] The TRL8 milestone for CSP is "Technology in its final form, connected to the grid" [8]

Table 8 Impact assessment of Horizon 2020 CSP projects

CSP IP R&I Activity	SET-Plan TRL Range	Relevant H2020 Projects	Comments (projects are in progress unless otherwise stated)
Improved central receiver molten salt technology	7→9	RAISELIFE (IA)	Materials development for reflectors, absorbers and HTF/TES
Parabolic trough with silicon oil (target 430 °C working temperature)	6→8	IN-POWER (IA)	Addresses range of topics including TES; target TRL 6-7
Next generation of central receiver power plants	6→8	RAISELIFE (IA)	Materials development for reflectors, absorbers and HTF/TES
Advanced linear concentrator Fresnel technology with direct molten salt circulation as HTF and for TES	6→8	RAISELIFE (IA) IN-POWER (IA) MOSAIC (RIA)	Materials development for reflectors, absorbers and HTF/TES Addresses range of topics including TES; target TRL 6-7 Innovative solar field + mirror: target TRL5
Parabolic trough with molten salt	6→8	PreFlexMS WP1 (IA) MSLOOP2.0 (FTIPilot) IN-POWER (IA)	Plant delays? Target TRL7 Target TRL7
Scale-up of open volumetric air receiver	6→8		
Multi-tower CR beam down system	5→7/8	CAPTure (RIA)	In progress, target TRL5
Thermal energy storage	4→7	SOCRATCES (RIA) GLASUNTES (MSCA) SESPer (MSAC)	Target TRL5 , thermochemical storage. + CO2 loop Combined receiver and TES, target TRL 3-4? Perovskite materials, , target TRL 2-3?
Supercritical steam turbines for CSP			
Advanced concepts for improved flexibility Topic 1 improved steam turbine operation Topic 2 Development of CSP plan analytics	 →3 3→6	 PreFlexMS WP2 (IA)	 Suspended? Target TRL7
Development of hybrid air Brayton turbine combined cycle sCO2 systems	3→6		
Pressurized air cycles for high efficiency solar thermal power plants	5→7	NEXT-CSP (RIA)	Particle receiver demo (up to 800 °C)

4 TECHNOLOGY OUTLOOK

4.1 Costs trends

While the marketability of STE electricity depends on several important non-technical elements, here the focus is on the capital investment and O&M costs, which can be influenced by technology development. **Figure 9** shows a compilation of historical and projected data for STE/CAPEX. To be consistent with the goals of the SET-Plan and Sunshot programmes, CAPEX for a nominal large plant (100 MW or greater) with 8 hour storage needs to come down to the level of 3 EUR million/MW from a current level of over 6 EUR million/MW. The lower prices of recent PPAs for STE plants in the Middle East provide an indication that progress is being made, but the values strongly reflect other critical factors such as financing conditions.

Overall the cost reduction effort needs to address all the main sub-systems (**Figure 10**), combined with gains in performance efficiency. The solar field (comprising here the reflecting systems themselves as well as the ground work costs) comprises approximately 40% of the CAPEX and is an obvious target.

Figure 9 Historical and projected CAPEX values for CSP parabolic trough and solar tower plants.

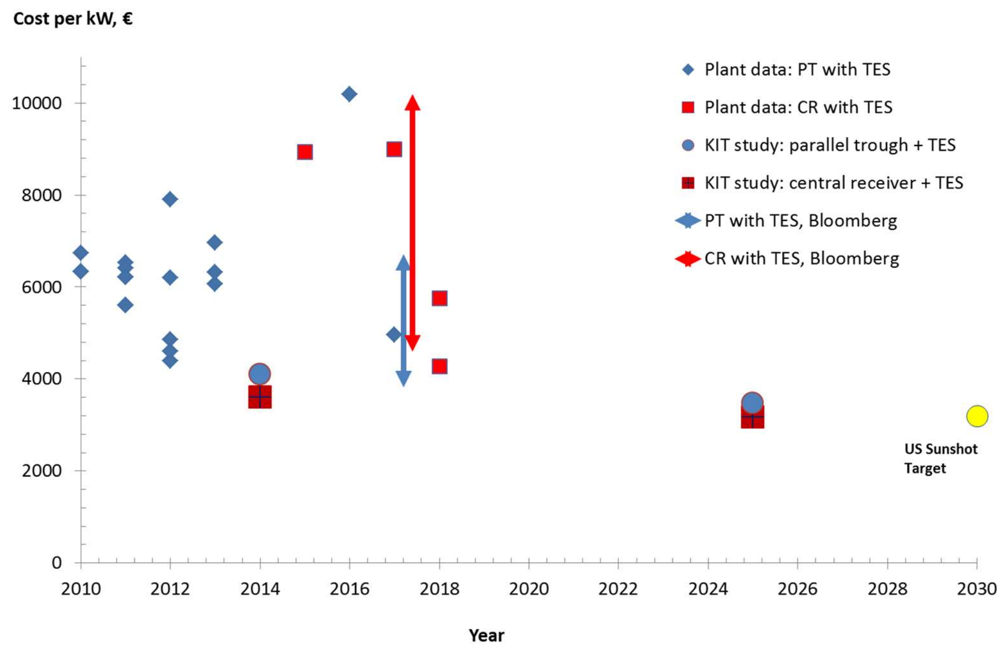
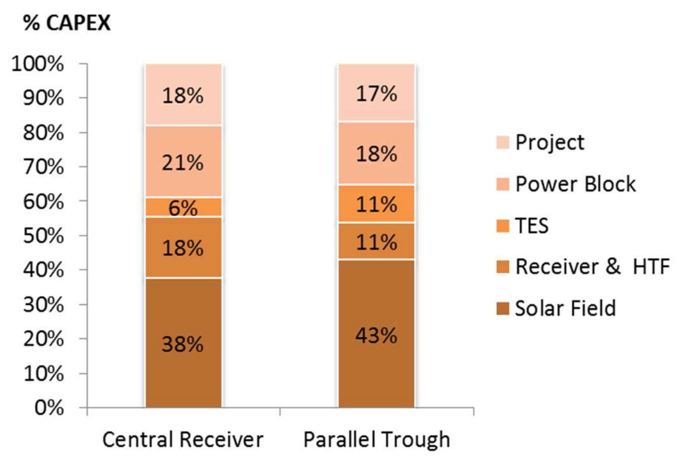


Figure 10 Distribution of costs between the main elements of CSP plants – (from data in KIC InnoEnergy 2014 [9]



4.2 Role of Technology Development for EU Deployment Potential

The JRC-EU-TIMES model offers a tool for assessing the possible impact of technology and cost developments. It represents the energy system of the EU28 plus Switzerland, Iceland and Norway, with each country constituting one region of the model. It simulates a series of 9 consecutive time periods from 2005 to 2060, with results reported for 2020, 2030, 2040 and 2050 [20]. The main scenarios are:

Diversified: Usage of all known supply, efficiency and mitigation options (including CCS and new nuclear plants); 2050 CO2 reduction target is achieved; overall electricity consumption grows by about 50% in 2050 compared to present levels.

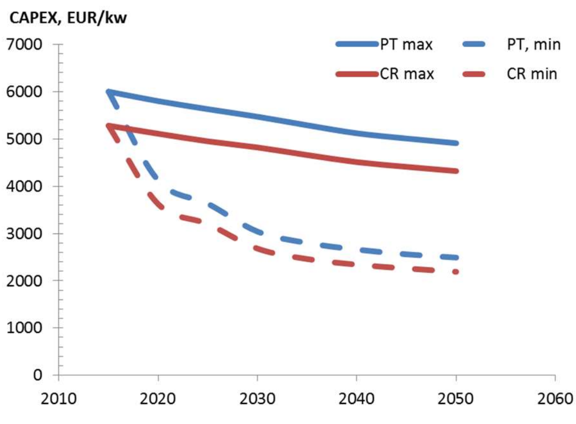
ProRES: 80% CO2 reduction by 2050; no new nuclear; no CCS; strong growth in electricity consumption, which increases by almost a factor of three compared to present levels.

The CSP-specific inputs include CAPEX and fixed operating and maintenance cost trends for a nominal 100 MW plant with 12 hours storage capacity for the minimum and maximum learning rate values (see **Figure 11**).

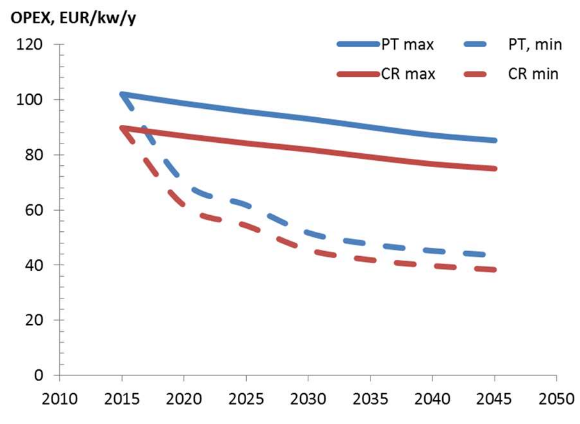
LCEO Deliverable report D4.7 presents the scenarios, the additional sensitivity runs and the overall results. This report focusses on the main CSP scenarios and the associated sensitivity runs for the high and low learning rates, considering the EU as a whole. Further analysis including country breakdowns will be included in the LCEO technology market report.

Figure 12(a) shows the total deployment of CSP plants in several major scenarios. For the Diversified scenario, the role of CSP is marginal with just 12.5 GW installed in 2050. The ProRES scenario foresees a more significant deployment of CSP, rising to 134 GW by 2050. In the Pro-RES SET-Plan (all technologies meet the SET-Plan performance targets) and the Pro-RES Near Zero Carbon scenarios the CSP role is further enhanced and significant new capacity added already in 2030. In relation to the sensitivity to the assumed learning rate for cost decrease, **Figure 12**(b) presents the impact of the high and low cost learning rates on STE deployment under the Pro-RES scenario (for these sensitivity cases the model applies the modified learning rates across all technologies, not just for STE). The high learning rate case produces a 45% increase in installed CSP for 2050 and the low value a 51% decrease, underlining the importance of achieving a sustained rate of cost reduction for CSP technologies.

Figure 11 Cost ranges for the nominal 100 MW STE plant (with 8 hours storage) used in the JRC-EU-TIMES model a) CAPEX and b) OPEX. The min and max relate to the highest and lowest cost learning rates observed in the output.

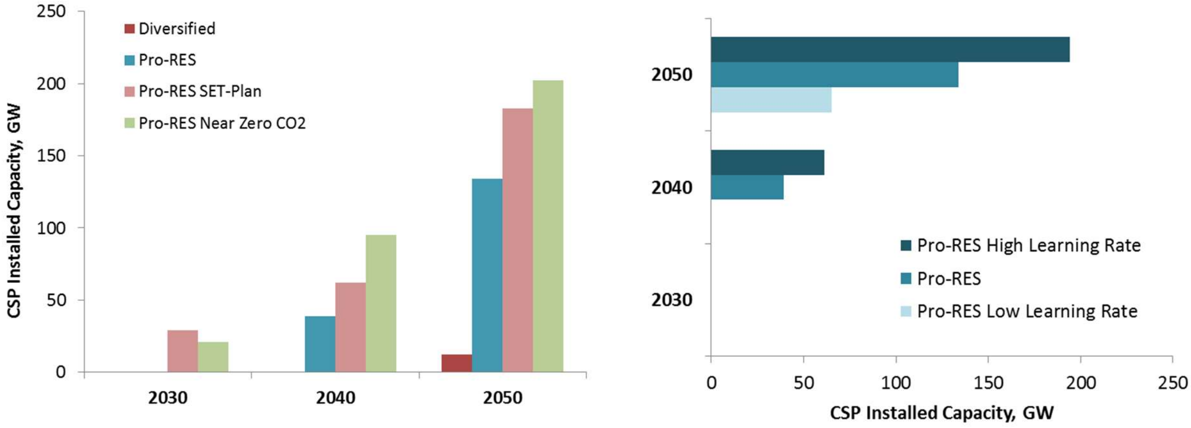


a) CAPEX



b) OPEX

Figure 12 CSP capacities in JRC-EU-TIMES model scenarios: a) comparison of the main scenarios and b) sensitivity to the technology cost learning rate for the Pro-RES scenario.



(a) comparison of scenarios (b) learning rate sensitivity

4.3 Challenges

As already stressed, cost reduction is fundamental and will become even more relevant as the cost of large grid connected battery systems comes down, allowing variable renewable sources such as PV and wind to offer dispatchability (currently a big advantage for STE). In this STE has to deal with its relatively complexity compared to other renewables. For instance PV has no moving parts, while wind, PV, ocean and geothermal all have only one energy conversion step.

To develop production volumes, one route can be to focus on establishing a small number of "standard" technology solutions. Depending on the market this can include large plants (> 100 MW) with the associated economies of scale but also a category of smaller modular plants to address specific market needs. In this respect it is hoped that the Horizon 2020 Coordination and Support Action MUSTEC can provide clear insights on viable technology-market combinations. For instance, a recent study on hybridisation options for STE plants (Omar, [21]) illustrated the complex range of technical options and some approaches to analysing these. Also, the US study on the future market value and role of sCO2 plants is an example [19]. For all system types, the development of state-of-the-art forecasting methods will be critical for competing in the day-ahead and intraday markets. Also consideration needs to be given to the potential impact of mitigation measures for environmental concerns, in particular water consumption.

Standardisation is also relevant at the scale of components and for installation qualification [22]. Progress is being made: ASTM is developing 'PTC 52 Concentrating Solar Power', which applies to testing of solar-to-thermal conversion systems for parabolic trough, power tower and linear Fresnel CSP systems. The IEC/TC 117: "Solar thermal electric plants" was set up in 2011 and currently has 8 working groups. From the European side this is being supported in particular by the Spanish Association for Standardization, Subcommittee CTN 206 / SC117 "Solar thermal electric plants".

STE is promoted as a commercially ready technology, but operating experience with the new generation of large-scale central receiver plants is scarce. Documentation of experience and best practices is becoming available at pilot plant level (for instance the recent review on molten salts thermal energy storage systems [23]) but more information is needed on long-term operating and maintenance costs.

Box 1 shows the six hurdles identified by Gauché el al [13], which provides a useful overview covering some of the above factors but also some non-technical ones.

Box 1: Six hurdles for CSP *(Gauché et al [13])*

1. Increased cumulative operating experience at plant level for CSP with storage.

2. The ability to learn, thereby following the cost learning curve, in part by a sustained growth rate and by shared learnings between developers.

3. Improving the technology to make bankability easier, in the form of operating experience but also by other means such as modularity to reduce the quantum of upfront cost.

4. The ability to prove systems and the integration value by demonstration and by refined systems analysis.

5. Social and environmental acceptance by factoring in all complexities and societal feedback.

6. A policy recognizing the energy security value of CSP, which shall be a part of a sustainable energy system, well ahead of the risk of conventional resource extraction decline.

5 CONCLUSIONS AND RECOMMENDATIONS

Deployment of STE technology is at an early stage, despite 30 years of research and development work. Two designs can be considered to be in full commercial application (TRL9): parabolic trough systems with thermal oil as heat transfer fluid, and central receiver/power tower systems, using steam or molten salt as heat transfer fluid. Even these plants are only just being realised at sufficient scale (>100 MW) to be cost competitive, and operational data and experience are needed to encourage significant investments.

The analysis of patent applications and of scientific publishing data underlines the leading R&I role of Europe and the USA, and a growing one for Chinese organisations. In Europe, effective collaborations have run over the last 20 years, aided by support from EU projects such as SFERA-I and SFERA-II and most recently the EU-SOLARIS Research Infrastructure initiative. This can become even more important in future. Focus is needed on effective support to the sector in Europe and the export of European technology.

Horizon 2020 has provided significant support to CSP/STE research, to date for about 25 projects with approximately EUR 89m contribution and a total budget in excess of EUR 100m. Almost all the 12 CSP IP R&I Activities are being supported to a greater or lesser extent, the exceptions being the volumetric air receiver concept and customised turbines for CSP with a supercritical steam power cycle. Overall, there is a focus on improving established systems (parabolic trough, linear Fresnel and central receiver), all with molten salt thermal storage systems. This contrasts somewhat with the strong push for sol-called Gen-3 supercritical CO2 cycles being launched in the US. The TRL targeted by the Horizon 2020 projects is in the range TRL6 to TRL7. All are still running (and indeed many are still at an early stage), so an impact assessment is not possible at this stage.

The CSP SET-Plan IP stressed the need for FOAK plants, but there has been no success in realising any of the concepts submitted for NER300. Nonetheless, some clarification of the strategy and prioritisation would be welcome, in the sense that FOAK plants are being proposed for different and not always compatible purposes: as innovative technology test beds, as feasibility scale-ups and as sources of operational reliability data.

As often stressed, cost reduction is fundamental and will become even more relevant as the cost of large grid connected battery systems comes down, allowing variable renewable sources such as PV and wind to offer increasing levels of dispatchability. This is underlined by the results of the JRC-EU-TIMES modelling scenarios of the EU energy system in 2050. To develop production volume, one route can be to focus on establishing a small number of "standard" technology solutions. Depending on the market analysis, this can include large plants (> 100 MW) with the associated economies of scale but also a category of smaller modular plants to address specific market needs, including hybridisation. Standardisation is also relevant at the level of critical components and for installation qualification; here project results and targeted pre-normative R&D can support current efforts at international level.

Operating experience with the new generation of large-scale central receiver plants is scarce. Documentation of experience and best practices is becoming available at pilot plant level but more information is needed on operating performance and reliability of commercial scale plants, to develop a basis for improved procedures, for design improvements and to develop investor confidence.

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ANNEX 1 – LISTING OF HORIZON 2020 CSP PROJECTS

Project No.	Acronym	Title	Type	Start	End	Overall Technical Objectives (summarised from project descriptions)	EC Contr, EUR	TRL start	TRL target
730609	MSLOOP 2.0	Molten Salt Loop 2.0: key element for the new solar thermal energy plants	FTIPilot	01/11/2016	30/04/2019	Develop a cost effective solar field for PTs using optimized ternary molten salts as HTF with an innovative hybridization system (HYSOL). - WP2 - Loop Prototype Advanced Development: check ternary molten salts with additives: minimize degradation up to 565 ºC and reduce freezing point below 140 ºC: dynamic loop testing, checking all the properties for 1000 h - WP3 System Manufacturing And Testing: detailed engineering of the loop prototype's main components obtained in WP2; test and validate systems. - WP4 Validation at Pilot Plant Scale	2 436 373	6	?
657690	ORC-PLUS	Organic Rankine Cycle - Prototype Link to Unit Storage	IA	01/05/2015	30/04/2019	Improve an existing CSP plant at the Moroccan Research Centre at Benguerir (ORC system , 1 MWe, linear Fresnel collectors, HTF mineral oil) - Increase thermal storage to 20 MWh, (approx. 4 hours production) - Assessment of two kinds of TES system (TRL6) - Demonstration of pilot plant in relevant environment (TRL7)	6 249 316	5	6/7
654984	PreFlexMS	Predictable Flexible Molten Salts Solar Power Plant	IA	01/06/2015	31/05/2018	1) Design and operate a molten salt once-through steam generator: existing technologies (molten salt + optimised control system) integrated for the first time 2) design and implementation of integrated weather forecasting and dispatch optimization: different approaches to DNI forecasting (direct; mesoscale models) to be integrated to extend geographical coverage and improve reliability. 4)Dispatch optimization for conditions of uncertainty (weather forecast) and perturbations (e.g. grid support requests). 3) a scaled-down pilot will be realized to demonstrate integrated operation of 1) and 2) .	14 362 194	6	7
686008	RAISELIFE	Raising the Lifetime of Functional Materials for Concentrated Solar Power Technology	IA	01/04/2016	31/03/2020	Focuses on five key functional materials for CSP: 1) protective and anti-soiling coatings for primary reflectors, 2) very high-reflective surfaces for heliostats, 3) high-temperature secondary reflectors, 4) receiver coatings, 5) corrosion resistant high-temperature metals and coatings for molten salts. Aims to achieve: • 2 different protective coatings for primary 4 mm silvered-glass mirrors	9 291 723	4-6	4-7

Project No.	Acronym	Title	Type	Start	End	Overall Technical Objectives (summarised from project descriptions)	EC Contr, EUR	TRL start	TRL target
						• 2 different anti-soiling coatings for silvered-glass mirrors • Primary silvered ultra-thin glass mirror • Secondary silvered high-temperature mirror on stainless steel substrate, for operation up to 350°C • 4 different High Solar Absorptance (HSA) coatings applied on metallic absorber tubes for ST (PVD, ceramic paint with and without aluminide coating and a multi metallic diffusion coating) for steam and molten salts • Absorption and transmittance coating for non-evacuated line focus collectors			
720749	IN-POWER	Advanced Materials Technologies To Quadruple The Concentrated Solar Thermal Current Power Generation	IA	01/01/2017	31/12/2020	- Develop high efficiency solar harvesting architectures based on holistic materials and innovative manufacturing process - Innovation focus on advanced materials such as high reflectance tailored shape light free glass mirror, high working temperature absorber in vacuum-free receiver, reduced mass support structures to allow upgrading current solar field. - Reduce environmental impact for 3 standard thermal storage systems; 4x reduction of the required land - Validation in LF and PT collector pilot plants	4 998 928	4	6/7
721045	NEXTOWER	Advanced materials Solutions for Next generation high efficiency concentrated solar power (CSP) tower systems	IA	01/01/2017	31/12/2021	1– Durable solar receivers, working under thermal cycling at a maximum materials temperature of at least 800°C and for 20 years. Options for exploitation with molten salt HTF or innovative liquid lead HTF/TES system. 2–Demostrate the durability of FeCrAl alloys at 700-900°C, thus paving the way to use of liquid lead as innovative heat transfer fluid. 3– New SOLEAD demo in Turkey of CSP with lead loop. Field testing for 12 months with lead at average 700°C 4–Develop harmonized protocols for the solar receiver and for the high temperature FeCrAl steels.	4 999 778	4	6
645725	FRIENDS2	Framework of Innovation for Engineering of New Durable Solar Surfaces	MSCA	2014		European network for the transfer of knowledge on surface engineering into innovative solutions for CSP. Abengoa, Uni. Cranfield, HZD - Rossendorf e.V., and one SME (Metal Estalki). Targets key components (reflectors, receivers and containers for heat storage) for high temperature applications. It includes computer modelling, multi-technique coating deposition, use of advanced characterization techniques, and the possibility of scaling-up new coating developments.	454 500		

Project No.	Acronym	Title	Type	Start	End	Overall Technical Objectives (summarised from project descriptions)	EC Contr, EUR	TRL start	TRL target
656753	GLASUNT ES	Innovative high temperature thermal energy storage concept for CSP plants exceeding 50% efficiency	MSCA	01/05/2016	30/04/2019	Study topics 1. innovative receiver co-located with the TES vessel. The solar radiation is directly absorbed by the liquid storage medium, and the thermal power is extracted by bubbling a gas through it (this can then be used for a Brayton cycle). 2. Use of common glass-forming compounds as novel TES materials 3. Systems combining the receiver–TES and power conversion units.	259 558		3/4?
746167	SESPer	Solar Energy Storage PERovskites	MSCA	13/11/2017	12/11/2020	Study on perovskites as storage media for a multilevel-cascaded TCS system. The main activities/objectives: 1. Perovskite synthesis by redox-precipitation method. 2. Tuning the perovskite thermochemical properties by the doping mechanism. 3. Enhancement of the heat transfer properties of the storage medium by shaping it in a porous form with high storage density. 4. Preliminary design of TCS system.	239 191		2/3?
640905	CAPTure	Competitive SolAr Power Towers – CAPTure	RIA	01/05/2015	30/04/2019	- Demonstrate a receiver operating at1200°C with a thermal efficiency of 80% for reduced LCoE, - develop a complete solar-receiver-Brayton-cycle unit and test in a relevant environment. - develop a low cost mirror field using small area heliostats and innovative control systems. - calculate the optimal parameters for a plant using the distributed tower concept.	6 104 033	3	5
654663	SOLPART	High Temperature Solar-Heated Reactors for Industrial Production of Reactive Particulates	RIA	01/01/2016	31/12/2019	Design and manufacture of two lab-scale solar reactors for particle treatment in energy intensive, non-metallic minerals industrial processes -pilot scale, a high temperature (950°C) 24h/day solar process suitable for particle treatment in energy intensive industries. - supplying the thermal energy requirement for $CaCO_3$ calcination by high temperature solar heat, with a 30 kWth solar reactor producing 30 kg/h CaO and a 16h hot CaO storage.	4 366 563		4/5
727762	NEXT-CSP	High Temparature concentrated solar thermal power plan with particle receiver and direct thermal storage	RIA	01/10/2016	30/09/2020	-Demonstrate at industrial pilot scale the validity of the particle-in-tube concept on the Themis solar tower. - Construct and test a 4-MWth tubular solar receiver able to heat particles to 800°C , a two-tank particle heat storage and a particle-to-pressurized air heat exchanger coupled to a 1.2 MWel gas turbine. - Design a commercial scale power plant (150 MW_e)	4 947 420	4	5

Project No.	Acronym	Title	Type	Start	End	Overall Technical Objectives (summarised from project descriptions)	EC Contr, EUR	TRL start	TRL target
727402	MOSAIC	MOdular high concentration SolAr Configuration	RIA	01/12/2016	30/11/2020	CSP modular configuration based on a fixed hemispheric semi-Fresnel solar field and a high temperature mobile receiver to decrease costs and increase cycle efficiencies. Molten salt receiver for the application will be designed, manufactured and tested. LCOE reduction of up to 20 %, below 0.11€/kW	5 077 734	3/4	5
727348	SOCRATCES	SOlar Calcium-looping integRAtion for Thermo-Chemical Energy Storage	RIA	01/01/2018	31/12/2020	Integration of the lime calcination process in CSP plants for thermochemical energy storage and power generation by means of a closed CO2 loop. Build a small scale prototype demonstrator in a relevant environment and plan for pilot plant after 2020 Claimed features - Reduced cost for energy storage system below 15€/kWh$_{th}$ - Temperatures above 850 ºC for high efficiency power cycle - Solar receivers temperatures below 700ºC for reducing costs - Mature Circulating Fluidized Bed reactor technology	4 994 153	4	5
697197	HELIOtube	Inflatable solar collectors for a low cost CSP Plant with irreducibly small carbon footprint	SME	01/11/2015	31/10/2017	Inflatable cylindrical concentrator made of plastic films, concentrates light by x100 and heats the thermal receiver fluid to 400 to 600°. Project technical objectives: 1. Engineering optimisation of the scaled-up collector (9m diameter, 7.5m mirror width, 220m long) and supporting structures. 2. Pilot production line for (partly automated roll-to-roll process); large scale products manufactured. 3. Field demonstration of a system with multiple tube elements	1 843 052	7	?
667942	CySTEM	Cyprus Solar Thermal Energy Chair for the Eastern Mediterranean	CSA	2014		Establish a cluster of researchers led by a professor of international stature to pursue a program of excellence in Cyprus	2 500 000	N/A	N/A
692259	NESTER	Networking for Excellence in Solar Thermal Energy Research	CSA	2015		Upgrading the scientific and innovation performance of the Cyprus Institute in the field of solar thermal energy in a network of excellence with CIEMAT, ENEA, PROMES/CNRS and RWTH – Aachen.	1 060 798	N/A	N/A
764626	MUSTEC	Market uptake of Solar Thermal Electricity through Cooperation	CSA	01/10/2017	30/09/2020	Consider the present and future European energy market design and policies as well as the value of CSP at electricity markets and related economic and environmental benefits.	2 396 526	N/A	N/A

Project No.	Acronym	Title	Type	Start	End	Overall Technical Objectives (summarised from project descriptions)	EC Contr, EUR	TRL start	TRL target
654443	MinWater CSP	Minimized water consumption in CSP plants	RIA	01/01/2016	31/12/2018	Next generation technologies for i) hybrid dry/wet cooling systems ii) wire structure heat transfer surfaces iii) axial flow fans iv) mirror cleaning techniques and v) optimized water management. -Reduce water evaporation losses by 75 to 95% compared to wet cooling systems. - Increase the net efficiency of the steam Rankine cycle by 2%, or alternatively reduce the capital cost of a dry-cooling system by 25%, at same efficiency. - Mirror cleaning water consumption reduced by 25% - Comprehensive water management plans for CSP plants in various locations	5 861 372	2-4	4-5
654479	WASCOP	Water Saving for Solar Concentrated Power	RIA	01/01/2016	31/12/2019	- Reduction in water consumption of up to 70% - 90% and a significant improvement in the water management - Topics/components addressed: hybridized cooler, adiabatic cooler, anti-soiling coatings , dust barriers, soiling detectors, ultrasonic cleaner, gravity lip system - Validation at four testing sites in France, Spain and Morocco	5 941 608	3	5-6
664000	TRANSRE GEN	Portable thermal fluid regeneration system for Solar Thermal Plants	SME Instru ment			- New high efficiency oil regeneration system for HTF synthetic oil in a compact & transportable design. - Design & validate technology in a relevant environment - Demonstration in real operating conditions.	50 000		
697271	TENCENT	The next generation of Hybrid Concentrating Solar Power Plants	SME Instru ment			Claimed unique CSP pilot plant. The basic unit of 1.5MW is called bCell, comprising: - patented tube collectors filled in with a novel HTF (>500ºC). - "Energy Center" to distribute or store the energy generated i	50 000		
705944	THERMOS TALL	High Performance Seasonal Solar Energy Latent Heat Thermal Storage Using Low Grade, Low Melting Temperature Metallic Alloys	MSCA			Develop a novel, cost effective and high performance Latent Heat Thermal Energy Storage System for seasonal accumulation of solar energy Use of low grade, eutectic low melting temperature metallic alloys with heat conduction two orders of magnitude greater than that of conventional PCMs Experimental studies of heat transfer and flow in a laboratory prototype of the LHTESS with ELMTAs will be conducted.	195 455		
706788	NPMSSES	Nanoparticle Enhanced Molten Salts for Solar Energy Storage	MSCA			Study on use of high conductive nanoparticles (NP) to improve the stability and thermo-physical properties of conventional PCMs Molten salts will be used as the matrix, and NPs (i.e., nickel, graphite platelet nanofibers and graphene) or expanded graphite.	195 455		

Project No.	Acronym	Title	Type	Start	End	Overall Technical Objectives (summarised from project descriptions)	EC Contr, EUR	TRL start	TRL target
711041	DIMONTEMP	Distributed Monitoring of HTF Temperature at Solar Thermal Power Plants	SME Instrument			Distributed monitoring of HTF temperature over the entire solar field for PT plants using optical fibres Reduction of HTF O&M cost of 38%	50 000		
718197	HELITE	High precision and performance heliostat for variable geometry fields of Thermosolar Plants	SME Instrument			Product for variable geometry designs of solar fields, allowing increased performance	50 000		

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