Initiative for Global Leadership in Concentrated Solar Thermal Technologies

Updated Implementation Plan

February 2023 (Original version – November 2017)

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I. Introduction and considerations about tender design

SET Plan[1] and EU energy policy context

The Communication *'Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation'*[2] was adopted by the European Commission (EC) on 15 September 2015 to reinforce the SET Plan as the technology pillar of the Research, Innovation and Competitiveness Dimension of the Energy Union. The Communication calls for greater prioritisation, integration, coordination and ownership by the SET Plan countries and stakeholders, and highlights the need to address gaps, duplications and synergies at the European Union (EU) and national level. To this end, it defines ten key priority actions to accelerate the energy system transformation in a cost-effective way, and calls upon the EC, SET Plan countries and stakeholders to co-operate to implement them.

Ambitious targets have been defined under the ten key priority actions of the SET Plan aiming to maintain (or regain in some cases) EU's global leadership on low-carbon technologies, with a particular emphasis on driving their costs down and improving their performance. For example, targets have been set for several renewable energy technologies with significant potential for cost reduction and large-scale deployment worldwide. The process for setting the targets has been highly participative engaging the SET Plan countries and a large number of stakeholders from research and industry. This joint ownership of decisions on prioritisation has enhanced the SET Plan's legitimacy regarding the strategic discussion on clean energy innovation at European level. Countries start to recognise the targets set as a strategic input to their energy programmes and policies. It is expected that this greater ownership will translate in a higher level of alignment between EU and national efforts, resulting in a higher impact regarding public investments as well as leverage of private investments.

In recent years, the EU's climate and energy ambition has increased significantly. In 2017 the EU adopted the Clean Energy Package, which included a binding 40% GHG emission reduction target and binding targets for 32% renewables and 32.5% energy efficiency improvements. In December 2019 the Commission President, Ursula Von Der Leyen, presented the European Green Deal (EGD)[3], as the new European growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient, and competitive economy. In practice, the European Green Deal, approved in 2020, is a set of policy initiatives by the European Commission with the overarching aim of making the EU climate neutral in 2050. This objective will require an overhaul of the energy system. Accelerating renewable energy deployment plays a central role in the success of the EGD. On 14 July 2021, the EC presented a comprehensive legislative package to deliver on the EGD (Fit for 55 package)[4]. It includes several proposals, being one of them the revision of the Renewable Energy Directive, setting forward the target to double the EU´s 2020 renewable share to reach at least 40% of final energy consumption by 2030.

During 2022, following Russia's military aggression against Ukraine, the European Commission published the REPowerEU Communication[5] where it emphasized the need to ramp up rapidly and efficiently the clean energy transition. The REPowerEU plan sets out a series of measures to rapidly reduce dependence on Russian fossil fuels and fast-forward the green transition while increasing the resilience of the EU-wide

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[1] See the latest edition of the strategic energy technology (SET) plan at: https://op.europa.eu/en/publication-detail/-/publication/064a025d-0703-11e8-b8f5-01aa75ed71a1

[2] C(2015) 6317 final

[3] The European Green Deal (europa.eu)

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0550&from=EN

[5] EUR-Lex - 52022DC0230 - EN - EUR-Lex (europa.eu)

energy system. Reducing our dependence on Russian and foreign fossil fuels will require a massive scale-up of renewables as well as faster electrification and replacement of fossil-based heat and fuel in industry, buildings and the transport sector. In this context, the European Concentrated Solar Thermal (CST) sector is ready to contribute to all these ambitious objectives. CST is a mature technology available to provide bulk storage capacities at competitive costs thanks to the large high-temperature thermal systems, offering flexibility to the electricity system by being capable of supplying large amounts of power at any time (day and night). If CST with Thermal Energy Storage (TES) partially meets the demand during the night, it could contribute to the progressive phasing out of the natural gas, with the corresponding decrease in the use of gas for electricity market. CST cannot replace the entire gas consumption but would definitely help to gain energy autonomy while reducing electricity prices for consumers. For the decarbonisation of industry, industrial processes can be decarbonised through CST at costs below renewable fuels or electricity-based options, providing and storing medium and high temperature heat with a remarkably high capacity factor (7,000h/year). CST has also great potential in harder-to-decarbonise areas, in the mid/long term, by developing new “green” fuels (“Green” hydrogen derivatives), allowing an efficient carbon-free operation at constant load and at high capacity factor.

The latest changes in the European energy policy context are calling for a revision of the SET Plan, aiming to make it more aligned with the “Fit for 55 package”, the 2050 decarbonization goal set in the EGD, and the REPowerEU initiative. The SET Plan must be reinforced, improved and considered, not only as the technology pillar of the Research, Innovation and Competitiveness Dimension of the Energy Union but also as a key step to better support the implementation of technology-related policies and programmes pursuing EGD objectives. The revision is expected in 2023. In this context, CST has a significant potential to achieve a very high renewable penetration. By June 2023 each EU member state is to update their National energy and climate plan (NECP) for 2021 - 2030 (interim update), which bring an opportunity to CSP/CST sector to be further integrated in these plans to decarbonise the Union.

Concentrated Solar Thermal Technologies (CST) as contributor to sector integration

The Paris Agreement and EGD, as recent major political initiatives at world and EU levels, have set high targets to reduce GHG emissions. In the light of CST, this decarbonisation challenge applies to three sectors, namely electricity, heating & cooling, and transport. It is expected that the decarbonisation of the power system will progress faster compared to the industrial and transport sectors, suggesting that the latter are facing complex challenges and will need more time and effort. In this direction, smart integration of CST in energy policies will result in innovative multi-technologies solutions impacting not just one, but the three sectors. While CST has a potential for decarbonising the heat in the whole of Europe, unfortunately, at the moment, it’s not sufficiently known to stakeholders.

Concentrated Solar Power (CSP) technology for electricity systems

By means of thermal energy storage, CSP [also defined as Solar Thermal Electricity (STE)] can make a significant contribution to the transformation of the European energy system by providing an important share of dispatchable renewable electricity. CSP is a carbon free electricity generation technology that facilitates the integration of variable output renewables (photovoltaics (PV) or wind energy), thereby contributing to the reliability of the transmission grid. In Europe, the best solar resources for CSP are to be found in the South, which makes this technology complementary to those renewable energy technologies that find their best resources in other regions of Europe. More specific to the technology pair CSP-PV, an operation pattern to produce electricity from PV during the day, while CSP generation starts after sunset, has large potential especially in Southern Europe. CSP power plants in combination with PV or wind offer the possibility to combine low power generation costs with very high full load hours in sunny areas. For example, integrated CSP-PV hybrid power plants, such as Noor I-II-III-IV in Morocco, use PV power to generate electricity during the hours of sunshine and use the CSP system to simultaneously charge the heat storage systemduring the day. If the sun does not fulfil the energy needs, the storage is used to provide heat for electricity generation (and, if applicable, heat). CSP plants can provide stability to the grid even with large amounts of variable electricity. This drastically reduces the overall system costs and enhances the high utilisation of grid infrastructure, which is one of the current main barriers to reach a higher RES penetration.

CSP can therefore contribute to meet the energy needs of large parts of the world, improving the **export opportunities for the European industry** and supporting the decarbonisation agenda of the Paris Agreement. Being aware of this, it must be highlighted that during the last years the growth in the CSP industry has been modest, due to policy changes and PV cost reductions that have led to complete halts in the former leading markets of Spain (in 2013) and the United States (in 2015)[6]. However, the geographic distribution of CSP has spread to countries such as Morocco, South Africa, Chile and China. Built-in thermal storage has become essential in all cases. Regarding the projections of different generation technologies, the IEA has defined three different scenarios (summarized within Table 1): Stated Policies, Announced Pledges and Net Zero Emissions.

Table 1. Definitions and objectives of the Global Energy and Climate (GEC) Model 2022 scenarios[7]

Scenarios	Stated Policies	Announced Pledges	Net Zero Emissions by 2050
Definitions	A scenario which reflects current policy settings based on a sector-by-sector and country by country assessment of the specific policies that are in place, as well as those that have been announced by governments around the world.	A scenario which assumes that all climate commitments made by governments around the world, including Nationally Determined Contributions (NDCs) and longer-term net zero targets, as well as targets for access to electricity and clean cooking, will be met in full and on time.	A scenario, which sets out a pathway for the global energy sector to achieve net zero CO2 emissions by 2050. It does not rely on emissions reductions from outside the energy sector to achieve its goals. Universal access to electricity and clean cooking are achieved by 2030.
Objectives	To provide a benchmark to assess the potential achievements (and limitations) of recent developments in energy and climate policy.	To show how close do current pledges get the world towards the target of limiting global warming to 1.5 °C, it highlights the “ambition gap” that needs to be closed to achieve the goals agreed at Paris in 2015. It also shows the gap between current targets and achieving universal energy access.	To show what is needed across the main sectors by various actors, and by when, for the world to achieve net zero energy related and industrial process CO2 emissions by 2050 while meeting other energy-related sustainable development goals such as universal energy access.

According to these scenarios, the projections to the years 2030, 2040 and 2050 within the world electricity sector, are recently being published by the IEA[8] and are indicated within the following tables 2, 3 and 4.

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[6] IEA. Solar Energy, Mapping the Road Ahead. October 2019

[7] IEA (2022), Global Energy and Climate Model, IEA, Paris https://www.iea.org/reports/global-energy-and-climate-model, License: CC BY 4.0

[8] IEA (2022), World Energy Outlook 2022, IEA, Paris. https://www.iea.org/reports/world-energy-outlook-2022. License: CC BY 4.0

Table 2. Word electricity sector projections. Stated Policies Scenario (CAAGR: compound average annual growth rate)[8]

	Stated Policies Scenario (GW)						Shares (%)			CAAGR (%) 2021 to:	
	2010	2020	2021	2030	2040	2050	2021	2030	2050	2030	2050
Total capacity	**5 198**	**7 849**	**8 185**	**11 954**	**16 468**	**19 792**	**100**	**100**	**100**	**4.3**	**3.1**
Renewables	1 343	2 989	3 278	6 707	10 666	13 653	40	56	69	8.3	5.0
Solar PV	39	741	892	3 020	5 573	7 464	11	25	38	15	7.6
Wind	181	737	832	1 830	2 853	3 564	10	15	18	9.2	5.1
Hydro	1 027	1 329	1 358	1 563	1 795	2 027	17	13	10	1.6	1.4
Bioenergy	83	160	173	246	327	406	2	2	2	4.0	3.0
of which BECCS	-	-	-	1	1	1	-	0	0	n.a.	n.a.
CSP	1	6	7	17	49	90	0	0	0	10	9.2
Geothermal	11	15	16	28	50	66	0	0	0	7.0	5.1
Marine	0	1	1	4	19	37	0	0	0	18	14
Nuclear	403	415	413	471	545	590	5	4	3	1.5	1.2
Hydrogen and ammonia	-	-	-	3	13	13	-	0	0	n.a.	n.a.
Fossil fuels with CCUS	-	0	0	1	26	33	0	0	0	28	21
Coal with CCUS	-	0	0	1	10	13	0	0	0	28	18
Natural gas with CCUS	-	-	-	-	16	20	-	-	0	n.a.	n.a.
Unabated fossil fuels	3 448	4 421	4 462	4 495	4 441	4 196	55	38	21	0.1	-0.2
Coal	1 621	2 161	2 184	2 129	1 936	1 583	27	18	8	-0.3	-1.1
Natural gas	1 389	1 830	1 850	2 074	2 268	2 422	23	17	12	1.3	0.9
Oil	438	430	427	292	237	192	5	2	1	-4.1	-2.7
Battery storage	1	18	27	270	768	1 296	0	2	7	29	14

Table 3. Word electricity sector projections. Announced Pledges Scenario (CAAGR: compound average annual growth rate)[8]

	Announced Pledges Scenario (GW)						Shares (%)			CAAGR (%) 2021 to:	
	2010	2020	2021	2030	2040	2050	2021	2030	2050	2030	2050
Total capacity	**5 198**	**7 849**	**8 185**	**12 932**	**20 258**	**26 541**	**100**	**100**	**100**	**5.2**	**4.1**
Renewables	1 343	2 989	3 278	7 744	14 510	20 290	40	60	76	10	6.5
Solar PV	39	741	892	3 498	7 471	11 065	11	27	42	16	9.1
Wind	181	737	832	2 251	4 246	5 727	10	17	22	12	6.9
Hydro	1 027	1 329	1 358	1 609	1 988	2 325	17	12	9	1.9	1.9
Bioenergy	83	160	173	307	529	707	2	2	3	6.6	5.0
of which BECCS	-	-	-	11	57	94	-	0	0	n.a.	n.a.
CSP	1	6	7	35	177	318	0	0	1	20	14
Geothermal	11	15	16	37	72	102	0	0	0	10	6.7
Marine	0	1	1	7	26	47	0	0	0	27	15
Nuclear	403	415	413	487	622	716	5	4	3	1.9	1.9
Hydrogen and ammonia	-	-	-	30	180	228	-	0	1	n.a.	n.a.
Fossil fuels with CCUS	-	0	0	18	192	288	0	0	1	74	31
Coal with CCUS	-	0	0	6	130	207	0	0	1	54	29
Natural gas with CCUS	-	-	-	12	62	81	-	0	0	n.a.	n.a.
Unabated fossil fuels	3 448	4 421	4 462	4 223	3 506	2 729	55	33	10	-0.6	-1.7
Coal	1 621	2 161	2 184	1 988	1 535	942	27	15	4	-1.0	-2.9
Natural gas	1 389	1 830	1 850	1 949	1 754	1 623	23	15	6	0.6	-0.5
Oil	438	430	427	286	217	164	5	2	1	-4.4	-3.3
Battery storage	1	18	27	425	1 246	2 286	0	3	9	36	17

Table 4. Word electricity sector projections. Net Zero Emissions by 2050 Scenario (CAAGR: compound average annual growth rate)[8]

	Net Zero Emissions by 2050 Scenario (GW)						Shares (%)			CAAGR (%) 2021 to:	
	2010	2020	2021	2030	2040	2050	2021	2030	2050	2030	2050
Total capacity	**5 198**	**7 849**	**8 185**	**15 306**	**26 870**	**33 878**	**100**	**100**	**100**	**7.2**	**5.0**
Renewables	1 343	2 989	3 278	10 349	21 398	27 304	40	68	81	14	7.6
Solar PV	39	741	892	5 052	11 620	15 468	11	33	46	21	10
Wind	181	737	832	3 072	6 435	7 795	10	20	23	16	8.0
Hydro	1 027	1 329	1 358	1 782	2 349	2 685	17	12	8	3.1	2.4
Bioenergy	83	160	173	320	585	744	2	2	2	7.1	5.2
of which BECCS	-	-	-	22	98	119	-	0	0	n.a.	n.a.
CSP	1	6	7	64	283	437	0	0	1	28	15
Geothermal	11	15	16	50	98	126	0	0	0	14	7.5
Marine	0	1	1	9	28	49	0	0	0	30	15
Nuclear	403	415	413	535	777	871	5	3	3	2.9	2.6
Hydrogen and ammonia	-	-	-	189	640	573	-	1	2	n.a.	n.a.
Fossil fuels with CCUS	-	0	0	62	266	335	0	0	1	100	31
Coal with CCUS	-	0	0	44	168	201	0	0	1	92	29
Natural gas with CCUS	-	-	-	18	98	134	-	0	0	n.a.	n.a.
Unabated fossil fuels	3 448	4 421	4 462	3 389	1 476	932	55	22	3	-3.0	-5.3
Coal	1 621	2 161	2 184	1 452	401	184	27	9	1	-4.4	-8.2
Natural gas	1 389	1 830	1 850	1 724	1 004	711	23	11	2	-0.8	-3.2
Oil	438	430	427	213	71	38	5	1	0	-7.5	-8.0
Battery storage	1	18	27	778	2 311	3 860	0	5	11	45	19

According to these projections, CSP is expected to contribute in 2030 with a total installed power of 17 to 64 GW, depending on the considered scenario. These figures, in the year 2040, increase to the range 49-283 GW and 90-437 GW in the case of the year 2050.

Main asset of CST plants for electricity systems

A major advantage of CST power plants is achieved by **integrating large high-temperature heat storage systems**. The storage of thermal energy, which is now technically proven and used in many places around the world, enables the provision of green solar power around the clock at competitive prices, regardless of solar radiation. The heat storage of CSP systems can thus provide solar power even at night when the sun is not shining. It is about 5-10 times cheaper than the storage of electricity. Besides supplying CO_2-free solar energy around the clock (24/7), CSP falls within the cost range of new fossil fuel-fired baseload power generation options[9]. With the integration of CSP technology, the energy supply system can be stabilised on a completely renewable basis at competitive prices. With a storage capacity of at least six hours and more per day, the power is supplied by CSP plants more cost-effectively compared to the use of PV systems coupled with batteries[9].

Another important technical factor that could strongly promote the deployment of CSP technology for electricity production in scenarios close to 100% of renewable energy generation, is the necessity of a specific amount of synchronous electricity generation to guarantee system inertia levels above the current critical ones and, consequently, sufficient grid stability. Advances in electronics and converters will certainly

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[9] IRENA, Renewable Power Generation Costs in 2021, https://irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Power_Generation_Costs_2021_.pdf

reduce the current inertia levels limit but the eventual feasibility of full disappearance of synchronous electricity generation from power grids is still unknown.

Hydrogen and SynFuel production by means of CST

Hybrid plants, as considered e.g., in the EU funded projects HYDROSOL-PLANT[10] and SUN-TO-LIQUID[11], can provide cost-effectively the energy for hydrogen production around the clock. Higher conversion efficiency levels are achievable, as the electrolysis system can run under constant load. It can thus be coupled to the (today) cheaper alkaline electrolysis technique (AEL) without any disadvantages. The high utilisation not only allows significantly smaller electrolysers to be used, but also makes much more efficient use of the necessary pipeline capacities. Initial estimates show that H_2 generation costs can be significantly reduced compared to wind or PV-powered PEM systems. Hydrogen production costs can be further reduced if high-temperature electrolysis (HTEL) is coupled with these systems. In addition to electricity, up to 20% of the energy can be supplied by high-temperature heat (200-800°C), which can be produced by concentrated solar thermal plants at a low cost. In this way, more hydrogen can be produced per year by the same power plant, while reducing the operating costs.

In the mid to long term, solar-thermochemical water splitting at temperatures above 800°C can also be a viable option to further reduce costs. Thermochemical cycles can directly convert heat into chemical energy by a series of chemical reactions. The direct application of solar heat in water-splitting thermochemical cycles for green hydrogen production allows operating at relatively moderate upper temperatures, reducing electricity consumption and reducing production cost. Besides hydrogen production, they offer the potential to produce syngas from water and CO_2 and thus opening a CO_2-neutral pathway towards synthetic hydrocarbon fuels and chemicals. The main technical challenges to be addressed are increasing the solar-to-fuel efficiency through process intensification, especially through highly efficient internal heat transfer and recovery as well as the scalability of the reactor concept to achieve high-energy conversion efficiencies and high throughput.

Heat for industrial processes as well as local and district heating by means of CST

The primary product of concentrated solar thermal technologies is heat. This can be used directly for the supply of industrial process heat and local and district heating. A large amount of heat is needed in the industrial sector within the range 60-300 ºC. By the end of 2021, at least 975 solar industrial heat plants (SHIP), totalling more than 826 MWth, were supplying process heat to factories worldwide[12]. This heat is used for a large range of processes and applications, implying around 24% of total global energy consumption (the industrial sector is responsible for 32% of global energy consumption and 74% of this energy is heat), supposing 85 EJ of global energy consumption in 2016. From this amount of energy, 30% is low temperature heat (below 150 ºC), mainly used in boiling, pasteurising, sterilising, cleaning, drying, washing, bleaching, steaming, pickling, and cooking. Medium-temperature heat (150 to 400 °C) represents 22%, used in processes like distilling, nitrate melting, dyeing, and compression. Finally, 48 % of the energy is used in high-temperature processes (above 400 °C), mainly for material transformation processes[13]. Below 150 ºC, conventional flat plate and evacuate tube solar collectors can be used but, in the upper ranges of temperatures, CST technologies are needed.

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[10] https://cordis.europa.eu/project/id/325361

[11] https://cordis.europa.eu/project/id/654408

[12] Renewables 2022 Global Status Report. REN21, 2022

[13] Solar Heat for Industry. Solar Payback, 2017.

Studies show that solar radiation allows attractive energy yields at competitive costs even in Germany and Denmark /Central Europe for district heating applications. CST produces adjustable heat between 50°C and 550°C. Most of existing heating networks require a water temperature range between approximately 60°C and 130°C (i.e., 60-70°C for small local networks and 80-130°C for district heating networks). Due to the achievable temperature range and its modularity, CST is therefore ideally suited for the supply of local and district heating. Existing heating networks and building technology can be used. In this respect, it is not necessary to remodel existing plants extensively and expensively. CST can also operate in combination with flat and evacuated tube collectors. These hybrid plants (CST & non-concentrated solar thermal) provide important synergies that allow for increased efficiency and lower costs, either for district heating or for industrial process heat.

The integration of heat storage systems (water storage) ensures a high degree of coverage and a more seasonally balanced supply of heat. When seasonal storage is used, 80-90% solar coverage can be achieved (without storage 10-20%). In combination with a heat storage system and with biomass or other thermal sources, heat can also be provided continuously. For local and district heating, line-focusing technologies, namely parabolic troughs, are used. This technology is well established worldwide. Point-focusing solar towers, on the other hand, are used when higher temperatures of up to 1,000°C are required. Currently, the investment costs of the parabolic troughs are approximately 200 - 300 €/m^2. However, the technology has not yet undergone cost regression due to the lack of serial production. From a solar field size of about 2000 m^2, the investment costs are of a similar order of magnitude as for flat collectors, according to manufacturers[14].

European global leadership in CST and its challenges

The European industry is a global leader in CST, with European entities involved in most of the projects developed so far worldwide. Yet, to maintain this global leadership, the European industry needs to stay ahead with more advanced, competitive technologies. Other countries are stepping up technology and commercial efforts in this field considerably, all targeting the same world markets as the European industry. In addition, innovation (new technologies reaching the market) needs to take place in Europe again, to maintain the confidence on European technologies of the international investors and promoters abroad. This is a very distinctive and crucial need of the CST sector. Due to detrimental non-technological framework conditions (see section III), Europe failed after 2010 (retroactive measures in Spain) to bring more CST technologies to the market (including first-of-a-kind (FOAK) commercial scale plants).

A further aspect is that a substantial capacity in conventional power plants will need to be shut down over the next years, especially in Southern Europe, because they reach the end of their useful lifetime. This can be a turning point for rebalancing the ratio between variable output renewables and dispatchable renewables in the European power system. CST innovation needs, therefore, further support to reduce costs via a combination of technology improvements, volumes deployed (learning curve and economies of scale) and risk-financing to support innovation projects. In addition, it is necessary to improve other framework conditions for FOAK demonstration projects and subsequent market deployment, including the ability to supply dispatchable electricity generated by CST plants from Southern Europe to Central/Northern Europe, thereby facilitating CST access to new markets.

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[14] https://www.deutsche-csp.com/technologie

Framework conditions in 2022. The Spanish tender

On 25 October 2022, the third tender of the Renewable Energy Economic Regime (REER) was held in Spain. With a total quota of 520 MW for solar thermal, biomass and photovoltaic, this tender had the following key boundary conditions:

- Pay as bid regime.
- The 520MW comprised a quota of 380MW, shared between biomass, solar thermal and some other renewable technologies, with a minimum reserve of 220MW for CSP and with a minimum capacity of 6 hours of full load storage. In addition, a quota of 140MW was reserved for distributed PV (to complete the 520 MW).
- Between 2,600 and 4,500 hours of CSP operation per year.
- Possibility of hybridization with photovoltaics as long as it does not exceed 10% of the CSP installed capacity, or biomass if the thermal boiler capacity is below CSP installed capacity.
- A 20-year revenue scheme.
- Market exposure of 15%.
- Revenues based on the following formula: $\text{Price}_{\text{tender}} + 15\% \text{ x } (\text{Price}_{\text{market}} - \text{Price}_{\text{tender}})$

The result of the 25 October 2022 CSP tender in Spain was void, as all the bids were above the maximum allowed price fixed by the national regulatory authority for this tender. The main reason behind such undesired result was the inadequate overall design of the process, as the tender rules, the existing high inflation, high interest rates and high commodity prices, the current high costs for transportation of goods and the uncertainty around grid access (among other reasons), did not reflect the real optimal cost of electricity of CSP.

The degree of interest of the CSP players has exceeded the minimum volumes of participation required by the tender regulation. In addition to the qualified bids, there have been others, totalling more than 500 MW, which have not finally submitted bids to the auction due to the uncertainty in getting grid access. As they do not have visibility on the date on which to opt for grid access, the candidates for the tender assume the risk that the tender is not called within a reasonable time to obtain grid access and the guarantee presented in the auction can be lost. Had the Spanish regulator given better visibility of its technology roadmap and greater certainty in getting grid access capacity, the tender would have probably reached a volume greater than 700MW, which shows the true interest and commitment to CSP.

Lessons learnt from the Spanish auction and recommendations to Member States about auction design

With the rapidly increasing share of intermittent renewable energy, the European transmission system faces higher and more volatile flows. Due to the firmness and inertia decrease, the electricity system may be at risk of being increasingly confronted with grid and stability congestions, redispatch measures (including RES curtailment) and loop flows. The need of more inertia, firmness and redispatch measures increase the cost of the system and diminish the market welfare. CSP, however, is key to security of supply and allows a non-intermittent and synchronous production of electricity, reducing the redispatch costs. By focussing on levelized cost of electricity only, the auction design of the 2022 Spanish auction did not reflect the true contribution of CSP to security of supply. As consequence, the CSP IWG would recommend to Member States to include in the auction design other elements concerning firmness, security of supply and system integration to capture the market welfare increase that a non-intermittent and synchronous production like CSP can help realise. More specifically, the following conclusions can be drawn from the Spanish auction result and could be added to the previous general recommendation to Member States:

- Firstly, it is irrational to force the competition, during the central hours of the day, between PV and CSP. The real benefit of CSP is its feasibility to provide electricity during the night, when PV can only compete with the addition of batteries.
- Secondly, hybridization (combined CSP+PV plants) is also key to achieve minimum electricity cost with round-the-clock dispatchability. This combination provide plants with high capacity factors also allowing the optimization of the needed investment for a defined amount of electricity to be delivered and should be allowed by the tendering process.
- Finally, other aspects of the tendering rules, such as longer time duration of the PPA or a minimum market exposure, are also equally important, as they could have a significant impact into the final offered price (CST requires a large CAPEX but its OPEX is very low).

Therefore, and as a general recommendation for other auction processes to be developed in Southern EU countries, future tender designs should be optimized in order to converge price bids into optimal CSP costs. Under reasonable optimized tender terms and rules, it is considered that current tender prices could reach levels below €150 per MWh.

It is clear that the design of the auction or tendering process can significantly affect the result and the final cost of the kWh. In addition, most of the international references related to costs on CSP/CST technologies are pre-COVID based and in the context of many years of financial stability. In 2022, after the COVID and in the mid of an intensive energy and economic crisis, tensions in the transports and commodities markets have caused cost overruns in supplies of over 30%. Therefore, the cost of the kWh of new power plants in Europe has increased, but due to non-technological reasons as the technology itself has not changed from the pre-COVID situation. Even more, during the last years, the sector has continuously worked to improve the technology and reduce costs.

This situation makes it necessary to outline the framework conditions considered as crucial to the achievement of the cost goals defined within the following section. The cost targets to be defined are related to the 2022 economic situation and any estimation or projection to the year 2025 or 2030 is assuming a minimum level of stability in economic magnitudes (inflation, interest rates, international transportation costs, etc.). Due to the current international and energy context uncertainty, it is very difficult to anticipate what is going to happen within the coming years, but **such targets should be properly adjusted if the general economic magnitudes do not return soon to a certain level of normality**.

Additionally, it is important to remark the importance of the global technology deployment in the process of cost reduction. Fig. 1 shows this process in the case of PV, wind and CSP technologies, being possible to observe a similar behaviour in PV and wind, with a rapid reduction in the initial cost until a certain inflexion point is reached (around 10 GW of global deployment), which could be associated to a certain full commercial maturity. CSP is still in the process, being difficult to achieve such commercial and cost maturity before, at least, the same level of 10 GW global deployment.

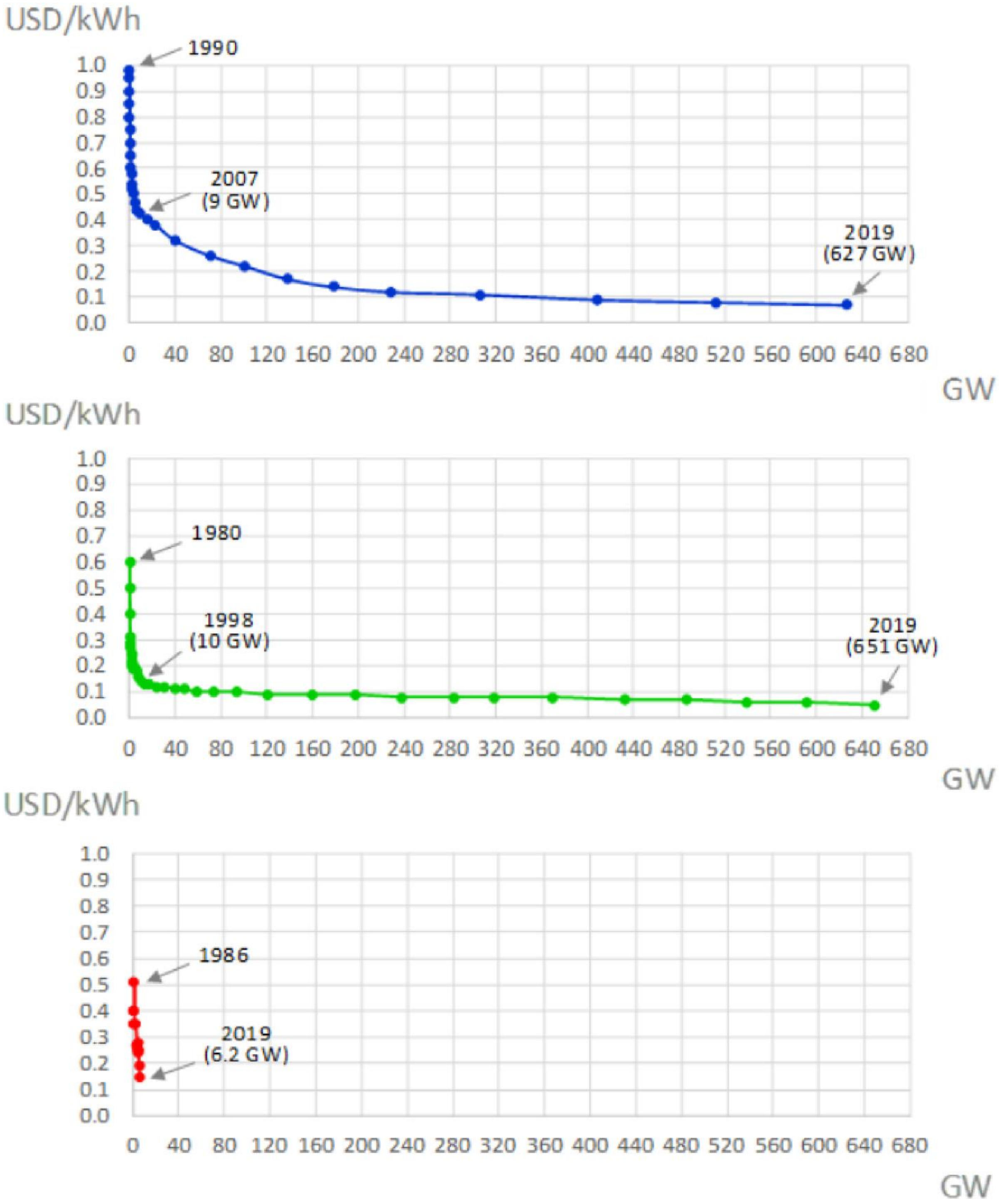

Figure 1. Historical global data evolution of weighted average LCOE of utility-scale PV (top), wind (middle) and CSP (bottom) projects (2019 USD)[15]

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[15] Energy 239 (2022) 122437. https://doi.org/10.1016/j.energy.2021.122437

II. Updated SET Plan strategic targets on CST

It is important to note that as of 2021, LCOEs below 10 c€/kWh have already been achieved in CSP plants in Dubai . The answer as to whether this paradigm can be replicated in Europe depends, amongst others, on several key factors besides the quality of the solar resources: market conditions and design parameters of CSP auctions in terms of PPA duration, exposure to market prices, inflation, PV hybridization, as well as time requirements between auction results and start of power plant operation.

Proposed new Strategic Targets:

The CSP IWG concluded that the previous 2015 targets should be updated as presented below (with the possibility to revise them in the future to accurately reflect the situation of the sector), focusing on five issues and their different building blocks as shown in Figure :

1. Cost reduction of electricity provided during periods with low wind, PV or hydropower infeed, to values below 15 c€/kWh in Southern Europe locations by 2025, targeting below 10 c€/kWh by 2030, considering 2050 kWh/m^2/year as reference conditions and no constraints regarding the size/type of the plant and Power Purchase Agreements (PPA) with a duration of at least 25 years. Also, the general framework conditions outlined in the previous section should apply.
2. Development of the next generation of CSP/STE technology (NEXTGEN) to achieve at least 3 points of increase in the overall power plant efficiency from the reference value 39.4 percent[16] to 42.4 percent by 2025.
3. At least one First of a Kind (FOAK) integrated in the energy system by 2025, demonstrating either the cost reduction or the efficiency increase.
4. Thermal energy cost for industrial process heat applications below 3 c€/kWh by 2030 for the same Southern Europe locations as the target 1, with process temperatures higher than 200°C and 25 years' lifetime.
5. Demonstration of 24/7 economically viable solar thermal baseload production of green hydrogen and other solar fuels by 2030.

The achievements of the strategic targets will depend, in addition to needed R&I developments, on a number of factors including non-technological framework conditions. This important issue was the main result of the EU-funded HORIZON-STE project[17], that concluded that only setting initial market conditions via legislation or initiatives translated into regulatory conditions will allow the suitable conditions for the emergence of a given technology with critical mass in terms of industry texture (sufficient number of industry actors), as the market mechanisms (competition on prices and technology performance) add efficiency to the market, but do not create initial demand for a technology.

This stands also true for the role of R&I that will improve competitiveness following the setup phase of the sector (see Chapter IV). R&I may deliver disruptive and, far more frequently incremental technological performance improvements. These can in turn allow the inclusion of innovations in commercial plants, so far, this is backed by de-risking measures, i.e., financial hedging support to reduce or offset the increased financial costs asked by financial institutions for innovations.

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[16] Official gross efficiency of 50 MW parabolic trough plant in Spain with Siemens turbine SST-700-RH (heat to electricity)

[17] https://cordis.europa.eu/project/id/838514

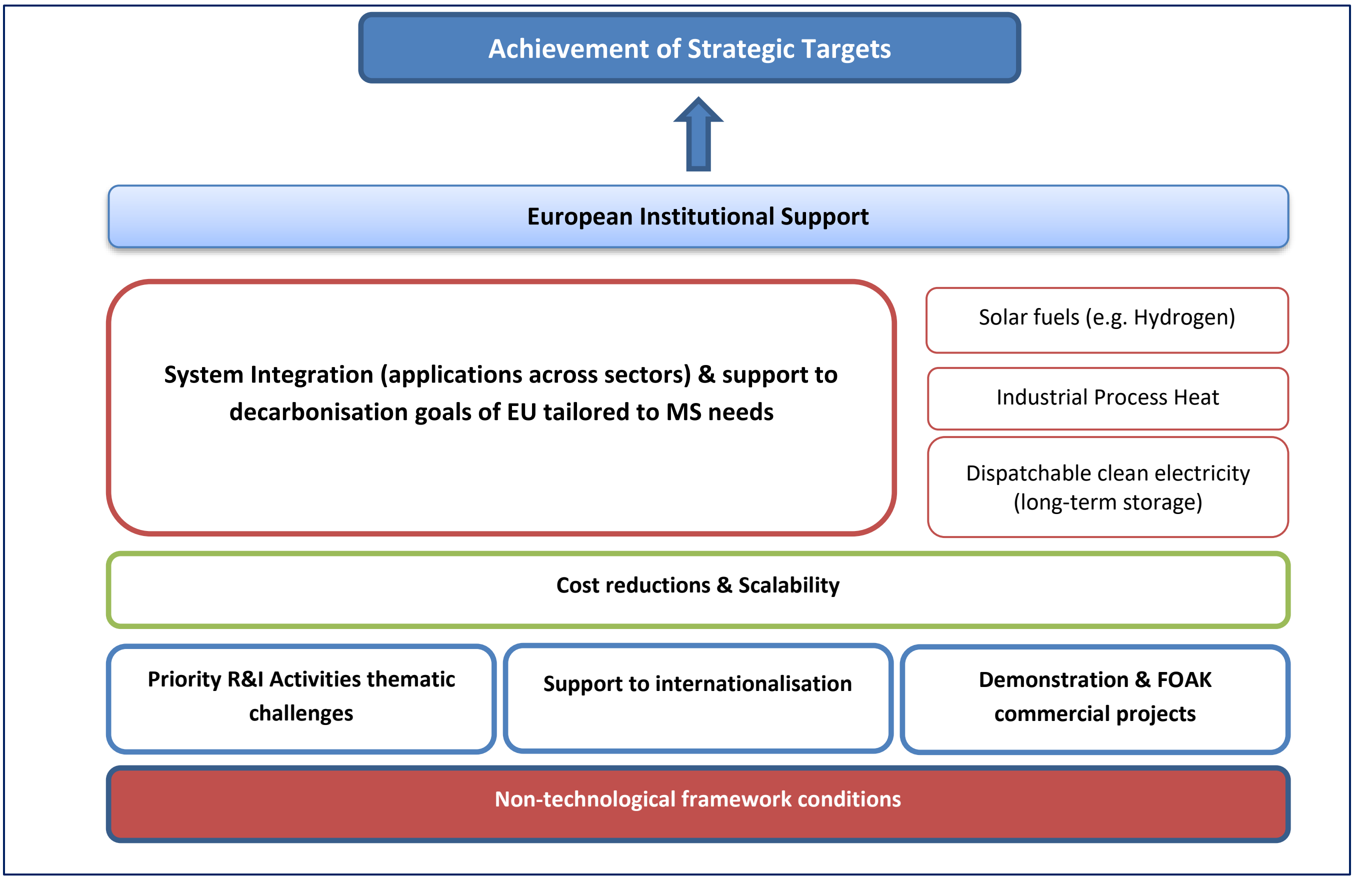

Figure 2. Building blocks for the achievement of the Strategic Targets for CST

III. Further considerations on non-technological framework conditions for CSP/CST

Deepening in the non-technological framework conditions, national representatives in the IWG pointed out that the essential elements affecting the deployment of CSP fell in the area of activity of other entities within their government structure (e.g., Ministries). This was the starting point of the CSA project HORIZON-STE. Following a selection of European countries identified as suitable for an efficient deployment of CSP/STE, HORIZON-STE identified the essential characteristics and potential shortcomings of current national strategies related to CSP/STE from a double perspective (R&I and industry) trying to showcase coherence and possible convergence of national endeavours.

Legal & Regulatory framework as essential boundary conditions to achieve the targets

Originally based on an approach to the CSP/STE limited to its use for the electricity sector, HORIZON-STE went bottom-up from the situation in the relevant European countries with focus on the boundary conditions affecting the procurement of manageable RES and it examined the working relations between R&I entities with their national funding agencies.

HORIZON-STE results provided new grounds for further support to the sector based on the following facts:

- As of mid-2022, there was a “new” interest for CSP that did not exist at the beginning of the project. This however did not yet result in a clear opening or programme. In particular:
    - Especially in Spain and to a lesser extent in Portugal, the perspectives for seeing new CSP power plants remain relatively realistic, since confirmed in the latest available updates of the respective NECPs.
    - But also, in Spain and Portugal, the interest of authorities contemplates various (hybrid) concepts incorporating parts of the CSP value chain able to support in the short-term the decarbonization of industry and later the development of new fuels, perceived as higher priority compared to the power system (already substantially decarbonized).
- The setup of a new market for CSP or CST depends primarily on the perceptions by authorities of whether (and if so, to which extent) this technology benefits the national economy and the current energy strategy ambitions. This national interest depends on:
    - the number and political “weight” of local companies susceptible to be involved in projects,
    - the availability of know-how and R&I capabilities in the country, and
    - the needs of the system and/or of the national economy at large.
- Nevertheless, no country so far has clarified, in its respective strategy and even less in the evaluation criteria of their respective procurement methods for new renewable capacities the correlation between apparent/artificial cost level (LCOEs) and a full cost approach (including the cost for necessary re-dispatching of intermittent sources shifted to overall system costs, for different intervals of refurbishments of plants over their effective lifetime, etc.).
- The costs of dependencies are generally assimilated to “force majeure” hazards. They discard the facts that these costs are always paid in time of crisis or emergency situations (COVID pandemic, invasion to Ukraine, etc.) and cannot be mitigated in the short and medium term - since they lead to a partial or total reset of industry/energy strategies that are only possible over decades.
- France is a specific case: it has good natural solar resources, several major companies with a strong industrial potential to promote CSP backed by extended R&I entities. This strong potential is however exclusively directed to non-EU CSP markets (Morocco, South Africa, UAE, China).
- A specific case study performed for Portugal revealed that a massive reduction of curtailments is achievable at a moderate higher cost (10% more cost with the effect of a 60% reduction of

curtailments) resulting from a more balanced participation of CSP in the Portuguese system. Furthermore, such a reduction of curtailments should not only be seen as an operational issue, but as a structural flaw of the RES capacity procurement mechanisms leading to market dysfunctionalities (regarding the awarded auction prices as well as non-financial support to more variable RES in the system).

- Strong priority is set on heat applications (in the short term) especially in Germany around the concept of “*Wärmewende*” (heat transition) with high ambitions towards a new H_2 market: the effects of this market are expected less for the electricity market than in the context of either developing new storage concepts (P2X, P2G) and/or new fuels for air transport. Legislative initiatives are expected in Germany (BMWK) in this respect.
- The use of CST for developing new applications in the post-oil area appears in a long-term focus of major EU oil companies, but as part of their respective strategy in some oil producing countries (OPEC), which have already implemented large CSP projects.
- In Italy, some progress was achieved via closer involvement of local communities in the project development that mitigated severe (almost systemic) issues of social acceptance affecting any major infrastructure project in the country.
- In all reviewed countries, clear signals were recorded to promote hybrid or cross technology projects binding the best available resources, which will be at the heart of the upcoming EU-funded project CST4ALL (coordinated by ESTELA).
- Because of the essential role played by national non-technological framework conditions, dedicated CSP lobbying platforms well-coordinated outside or within the overarching general representation of the renewables industry should be set up. Their action should be directed towards the respective policymakers and the related regulatory environment to demonstrate the maturity of the industry in all its value chain segments to quickly offer solutions (doubling the installed thermal storage capacity in Spain within 1 year).
- Finally, TSOs are aware of the future storage needs in case of a further deployment of variable renewables but cannot yet confirm the ability of adding dispatchability support to existing low-cost technology due to the regulatory lack of control on the use of storage (according to the legislation at construction time).

Use of the cooperation mechanisms in the Renewable Energy Directive

The SET Plan countries are encouraged to investigate their interest to participate in cooperation mechanisms under the Renewable Energy Directive for FOAKs and their willingness to support such projects (including financially) to reach the targets. This includes not only SET Plan countries interested in deploying CSP or in developing CSP technologies, but also those countries interested in importing dispatchable renewable electricity generated by CSP plants to achieve their 2030 renewable energy targets. This was underlined in the results of the Horizon 2020 project MUSTEC[18].

In 2016, Germany and Denmark focused on ground-mounted photovoltaic systems and on the principle of reciprocity (both countries must give access to their auctions). In the view of the CSP IWG, the CSP Initiative should aim to achieve first dispatchable renewable energy projects based on similar cooperation mechanisms.

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[18] https://cordis.europa.eu/project/id/764626

Speed up and facilitate the permitting process in SET Plan countries (and if appropriate their regions)

Excessively long permitting processes may significantly hinder innovation. It was clarified that two main types of permits are needed for a CSP plant – environmental and administrative authorisations. In addition, grid access can be an issue. SET Plan countries are encouraged to report on cases where their regulatory framework has hindered the development of CSP projects because of permits and grid access. The REPowerEU Plan[19] foresees actions for accelerating the permitting procedures.

Financing

It is essential to ensure optimal coordination and synergies of all funding resources potentially available. In practical terms, it is fundamental that the financing conditions available to European developers would be comparable to the ones already existing outside Europe. For the CSP IWG this includes the following needs:

- Ensure co-financing by SET Plan countries and the EC, including the alignment of national programs. In this line, the Clean Energy Transition Horizon Europe Co-funded European Partnership aims to empower the clean energy transition and contribute to the EU's goal of becoming the first climate-neutral continent by 2050, by pooling national and regional RDTI funding for a broad variety of technologies, including CST, and system solutions required to make the transition.
- Better coordination with structural funds: facilitate the use of structural funds in much better coordination with EU and national grants and financial instruments
- Risk financing reduction

A preliminary program for financing large CSP projects was the NER 300. The status of the NER 300 CSP projects was raised by the industry and discussed at length by the CSP IWG. There is a clear need for a sufficiently high-degree of coordination and synergies of supporting instruments. Almost none of the six CSP projects which were included in the final list of awardees has reached the financial close yet – and there are indications that some of them will not go ahead. This implies that a total NER 300 'award' amount of approximately 300 million EUR is currently frozen without the possibility to influence positively R&I in Europe in this sector. One of the reasons for this outcome seems to be that the NER300 applicants were left struggling to complete the financial close in market conditions which are unfavourable (the NER 300 awards represent indeed a substantial amount of funding but cover only 20-30% of each plant's cost).

Table 5. The CSP NER 300 projects

Project Acronym	Country	Technology	Year of award decision	Award amount (million EUR)
HELIOS POWER	Cyprus	Stirling dish	2012	46,6
MAXIMUS	Greece	Stirling dish		44,6
MINOS	Greece	Solar tower		42,1
PTC50-ALVARADO[20]	Spain	Solar tower		70,0
EOS GREEN ENERGY	Cyprus	Solar tower	2014	60,2
MAZARA SOLAR	Italy	Solar tower		40,0

For this reason, the CSP IWG considered that a much more comprehensive and coordinated approach in terms of financing sources is needed. In addition, the IWG agreed that the EC and the Member States should examine the possibility to channel (at least) the unspent amount of 300 million EUR of NER 300 CSP grants

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[19] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

[20] The Spanish authorities have confirmed that this project is withdrawn.

to support the FOAKs (see following chapters).

The Innovation Fund, successor of NER 300, is one of the world's largest funding programmes for the commercial demonstration of innovative low-carbon technologies, aiming to bring to market industrial solutions to decarbonise Europe and support its transition to climate neutrality. Among the wide range of financial instruments available on the EU level, it plays a unique role due to its size and focuses on the last steps in the rollout of innovative clean technologies. The Innovation Fund improves risk sharing for projects by giving more funding and flexibility through a simpler selection process. The aim is to share the innovation risk with project promoters to support first-of-a-kind highly innovative projects and to make the European industry a global leader in clean technologies. It is open, among others, to projects focused on innovative renewable energy generation, and is considered by the CSP IWG as one of the most relevant European programmes to support the FOAK (see following chapters). The Innovation Fund will provide around EUR 38 billion of support from 2020 to 2030, depending on the carbon price. The Innovation Fund aims to ensure synergies with other investment support instruments, such as InvestEU or lending programmes of the European Investment Bank, and other relevant EU funding programmes, such as Horizon Europe or Connecting Europe Facility.

IV. Priority technology actions (R&I Activities)

Proposed areas of IP activity

Until now, the R&I Activities of the CSP implementation plan were fully focused on high TRL topics and electricity production technologies with the objective to develop innovations with the potential to be eventually transferred to commercial projects. This approach needed to be changed to, firstly, open the range to lower TRL key actions with the capacity to improve efficiency, durability and reliability as well as cost reduction and, secondly, to add other important applications such as industrial process heat and solar fuels development. The list of proposed areas of CSP-IP activity is defined and explained as follows:

- **Line-focus solar power plant technology.** This technology is the most developed at a commercial scale as the shorter focal length of line-focus concentrators makes this technology more attractive for sunny places with a certain level of atmospheric attenuation. The use of working fluids thermally stable at temperatures higher than 425°C would increase the power block efficiency. In addition, there is still a margin to reduce the solar field cost and the maintenance effort demanded by some key components at present, like the receiver tubes and the elements used to connect the receiver tubes of adjacent parabolic trough and linear Fresnel collectors. In addition, the assessment of the potential suitability of molten salt use within parabolic trough technology is considered and should be finally addressed and determined.
- **Central receiver power plant technology**. Besides its lower commercial deployment, tower technology has higher efficiencies than line-focus plants due to its higher working temperature and thermodynamic cycle efficiencies. At present, the most mature technology for commercial plants is based on molten-salt receivers; however, these systems need further advancement, already identified, in cost reduction and increased competitiveness. In parallel, several innovative concepts, materials and components for central receiver technology should be explored. Among these, innovative plant field designs (e.g., multi-tower approaches or beam down) and particle receiver development, can be highlighted.
- **Reliable and cost-effective medium and high-temperature Thermal Energy Storage (TES).** Dispatchability is the main benefit of solar thermal electricity vis-a-vis other renewables such as PV or wind. This dispatchability is provided by the thermal energy storage systems. The working temperature of the storage systems commercially implemented at present in solar thermal power plants is either 390°C or 565°C, depending on the storage media (diathermic oils or molten salts). This already commercial solution can be improved in terms of energy density storage and cost-effectiveness through innovative storage configurations and the use of combined sensible/latent heat systems. Anyway, the current storage temperatures are not high enough for supercritical steam Rankine cycles or Brayton cycles with supercritical CO_2 (sCO_2 cycles), which would have higher efficiencies. The development of thermal storage systems for $T > 600°C$ is needed to allow the implementation of supercritical steam Rankine cycles, while thermal storage for $T > 750°C$ is required for tower plants with sCO_2 or Brayton cycles. The nature and storage medium for these two temperature levels are likely to be different and the technical constraints will be different too (e. g. solid materials promise cost-effective solutions for high temperatures).
- **Turbo-machinery** is to be developed for specific conditions of solar thermal power plants. Turbine manufacturers have pointed out that the use of steam turbo-machinery specially designed taking into consideration the technical and operational constraints of solar thermal power plants could increase the overall plant efficiency, which in turn would increase the competitiveness of solar thermal power plants. Turbomachinery specially designed for the specifications of highly competitive solar thermal power plants would enable higher overall plant efficiencies, improve

operational flexibility and reduce maintenance costs. In addition, sCO_2 cycles, are a very promising option for CSP applications so the development of adequate turbo-machinery is obviously an essential step.

- **Medium-and high temperature systems for industrial solar heat applications**. About 40% of the thermal energy consumption in the industrial sector is within the range of 60–300°C. These systems are often relatively small, which result in the demand for a robust and highly automated system to reduce O&M cost and to increase the efficiency of the solar system for industrial processes. However, the CST sector still needs the development of highly autonomous solar fields to further reduce maintenance requirements and to increase the amount of thermal energy delivered to the industrial process. Also, significant cost reductions may be additionally achieved using direct steam generation, which has many advantages over the use of thermal oil or pressurized liquid water as working fluid in line-focus solar fields. For high-temperature industrial heat applications with temperatures up to 1000°C the development of suited receiver materials, technologies and autonomous solar fields promises to provide low-cost thermal energy and significantly reduce the carbon footprint. Standardized solutions for solar integration to industrial processes show large potential for acceptance and cost reduction.
- **High temperature solar fuels production**. Concentrated solar energy systems can be employed in the production of “solar fuels” (any chemical compound that can react with oxygen releasing energy), using two possible approaches. One of them is the so-called solar thermochemical processes, where high-temperature heat is supplied as the necessary energy source for the performance of endothermic chemical reactions to produce chemical substances that can be used downstream in the chemical industry for the synthesis of liquid hydrocarbon fuels or ammonia, or stored/transported and used for off-sun electricity production when and where needed. Alternatively, in electrochemical processes, CST systems with their function as electricity providers can supply (in addition to other renewable sources like photovoltaics or wind power) the renewable electricity for electrolysis of steam. Obviously, CST systems can provide both the electrical and thermal energy required for several hybrid processes which use electricity as well as thermal energy. Up until now, such CST-driven processes for solar fuels production involve reforming and gasification of carbon-containing feedstocks, or thermochemical water/carbon dioxide splitting cycles employing either sulphuric acid (for water splitting only) or redox oxides. With respect to the latter, currently, technical solutions based on reactors without high-temperature moving parts, incorporating the maximum possible redox material quantity per volume and integrating efficient schemes of heat recovery, seem to offer the easiest way to scale-up beyond the lab-scale level and significant progress in such solar reactor design has been made. Indeed, the full process value chain from CST-driven syngas production via water and carbon dioxide splitting to liquid hydrocarbon fuels has been shown to be technically feasible at a pilot solar field/reactor level, but no such process has been so far demonstrated at the several hundred kW level and relatively long-term operation.
- **Crosscutting issues.** In addition to the previous areas of activities, some crosscutting topics are relevant and considered necessary to be included within this updated Implementation Plan. Among them, the full integration of CSP and PV technologies into a single power plant. CSP and PV are mature as separate technologies, but there is plenty of room to implement as a single unit as existing PV/CSP plants operate independently and are not hybridized. Such integration can provide a significant cost reduction of fully dispatchable and flexible power, targeting 24/7 production. Another important topic is the digitalization of CSP/STE plants can provide a significant advancement in the achievement of more efficient monitoring and, therefore, better operation and maintenance of the plants. In addition, another relevant issue to be addressed within this final

area is to raise general awareness, not only by the public but also by energy planners, TSOs, DSOs and policymakers, of the benefits that CSP/STE can provide to the electrical system. To this end, specific initiatives to promote the further deployment of CSP are considered needed.

Regarding the financing of associated activities to the previous research areas, it is essential to establish a framework to ensure effective coordination between public funding at EU, national and regional levels (ideally with a single submission point) and to mobilise private investment with strong leverage effect. Additionally, such implementing framework needs, in addition, to be highly inclusive and transparent. Potential options for implementation instruments to execute this IP are the following:

- Horizon Europe Programme
- Clean Energy Transition European Partnership
- National Energy and Research support programs:
    - German Energy Research Framework Programme
    - Federal Ministry for Economic Affairs and Energy (Germany)
    - Helmholtz Program on Renewables (Germany)
    - Italian Electric System Research program (2022-2024)
    - Support from CDTI to technological development and industrial innovation (Spain)
    - Support/grants from MICINN to research activities (Spain)
    - Greek R&D Framework Programme (2021-2027)
    - Grants from Research Promotion Foundation (RESTART) and other structural funds (Cyprus)
    - Support/grants from National and Regional funding Programmes, such as: Portugal2030 / Alentejo2030 / FAI – Fundo de Apoio à Inovação to R&D activities (Portugal)
    - Regional and National funds (France)
    - Regional funds (all countries)
- National Recovery Plans (all countries)
- Innovation Fund Programme
- International cooperation schemes: bi-lateral programs between Europe and South America or Europe and Africa
- Contributions from European CSP/STE companies
- Contributions from European chemical and petrochemical companies, gas providers, energy utilities
- In-kind contribution from research and partner organizations

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V. Demonstration projects at commercial scale (First of a Kind – FOAK)

Context for the demonstration projects at commercial scale

In the CSP sector, there is at present a serious market failure in Europe. As a result, the market introduction of new CSP/CST technologies developed in Europe is currently taking place in other continents. However, having innovation taking place and tested in Europe is essential for the European industry to keep sustained global leadership. CSP/CST deployment and innovation, now in a standstill situation in Europe, need therefore to be reactivated.

It should be noted that given the important amount of engineering involved in CSP plants and further uses of the technology for process heat and solar fuels production, the industry estimates that the first replication of a FOAK (what could be referred to as the 'second of a kind') could achieve additional cost reductions of about 10-20% thanks to the learning curve only – which would diminish the amount of innovative financing support required for subsequent replications.

The CSP IWG concluded that FOAKs are a fundamental step to re-activate the deployment of CSP in Europe and that priority should be given to deployment efforts that demonstrate the validity of the cooperation mechanisms set out in the Renewable Energy Directive.

Main requirements for FOAKs

The IWG agreed that the FOAKs should meet the following requirements:

- Demonstrate at commercial scale crucial technology solutions to reach the targets
- Include storage in order to provide fully dispatchable power, and to allow for more flexible generation (to power production but also in the case of process heat applications)
- Have a high potential of replication in Europe or other world regions
- Make use of the cooperation mechanisms of the Renewable Energy Directive (thereby facilitating access to new markets in Europe)
- Combine innovative financial instruments (loans and loan guarantees), complementing grants and structural funds (together with the equity side by the promoters in project finance)
- Have a business plan which includes an agreement with an off-taker interested in the high value of CSP dispatchable electricity
- Have a clear dissemination plan that indicates how essential findings from the FOAKs can be made available to the public in order to facilitate fast follow-ups.

The IWG considers that **at least one FOAK should be implemented in Europe in the coming years**. The objective should not be a one-shot project, but to create a framework/scheme. This is in line with the outcome of the ICF study tendered by DG RTD on financing needs for FOAKs projects on SET Plan technologies, according to which between five and ten new CSP FOAKs was seen as necessary in Europe by 2020[21].

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[21] https://setis.ec.europa.eu/system/files/2021-01/setis_funding_magazine_april_2017_web.pdf

The choice of the innovative technology solutions proposed in the FOAKs should be up to the promoters – they should not be prescribed by the IP. The promoters will need to reach the cost reduction targets with the innovative technologies they deem most suitable for this purpose.

Innovative financing to support demonstration projects at commercial scale

This issue has been examined by ICF in their study, in which it is estimated that an approximate investment of 0.9 - 3.3 billion EUR would be necessary for the CSP FOAKs.

Considering the high costs of CSP FOAKs, to finance such projects, it is necessary to achieve a well-coordinated financial engineering involving many elements relating to very different entities, which generally include:

- a project finance scheme (as opposed to corporate finance) involving
    - In the equity side ideally grant support (in addition to the own resources from the promoters)
        - R&I: support (EU, national, regional…) for the innovative part of the project
        - Structural funds support to the infrastructure side of the plant when appropriate
    - In the debt side, ideally, involvement of the European Investment Bank using its own instruments, or InvestEU, or risk-sharing instruments with the EC. This would facilitate, in addition, the participation of other financial entities in the debt-financing of the project
- the agreement with an off-taker interested in the high value of CSP dispatchable electricity

To achieve such a complex engineering, it is necessary to ensure a sufficiently high degree of coordination of supporting instruments at the EU, national and regional level, including structural funds, as well as equity and debt public and private financing.

In addition, if the cooperation mechanisms of the Renewable Energy Directive are applied, it is necessary to have in a project at least two Member States ('deployer' and 'off-taker') involved in the discussions.

VI. Support to internationalisation

International cooperation on CSP can significantly contribute to the achievement of the targets and to maintain global leadership from at least four angles, depending on the effectiveness of the actions taken:

- R&I cooperation based upon excellence to accelerate the development of new/breakthrough CSP technologies.
- R&I cooperation intended to develop technology suited for specific world regions which would lead to overall cost reductions and would facilitate the subsequent market penetration of European companies.
- International cooperation/relations beyond R&I, but closely related to R&I, to support the global competitiveness of the European industry (issues of market access, international trade, development aid supporting the deployment of innovative technologies in other regions, etc.).
- International cooperation objectives stemming from the Paris Agreement, including possibly within the framework of Mission Innovation, and also to support investment in the deployment of innovative clean technologies in developing countries.

The CSP IWG acknowledged the potential benefits stemming from cooperation with countries in the Arabian Peninsula or in North Africa as being regions where European companies can compete with other technology providers.

The IWG considered that it would be very helpful if R&I international cooperation helps to establish bridges between European stakeholders and planners and policy makers in different world regions regarding the value proposition of (dispatchable) CSP.

VII. CST research facilities contribution

The execution of the implementation plan will require the full availability of existing world-class research facilities and their future upgrading. To this end, the EU-SOLARIS ERIC (European Research Infrastructure Consortium), which is formally defined as ESFRI Landmark, is considered as a key asset.

EU-SOLARIS[22] has the main objective of improving the interoperability, accessibility and quality of the installations (testbeds, demonstrators, pilot facilities, equipment, living labs, etc.) and services provided to the CSP research community. Initially constituted by Spain, France, Germany, and Cyprus, with the addition of Portugal as observer, EU-SOLARIS ERIC will continuously assess how it could better contribute to the execution of the implementation plan. Formal constitution and launching of the organization takes place in January 2023.

In addition to the periodic contribution of member states, the activities can be co-funded by public funds/grants and services to the private sector, such as:

- R&D services.
- Access to research infrastructure services.
- Research infrastructure testing services.
- Training and dissemination activities.

The EU-SOLARIS ERIC strategic objectives are the following:

1. Coordinating, as a single infrastructure of a distributed nature, the main R&D facilities existing in Europe.
2. Providing a single User Entry Point to R&D facilities and resources for the CSP research community.
3. Strengthening collaboration between scientific institutions, academia and industry.
4. Identifying new requirements for the improvement of research facilities and for the construction of new ones, when necessary.
5. Identifying and establish the best research and experimentation practices, leading and coordinating the open dissemination of results and experimental data.
6. Maintaining Europe at the forefront and leadership in the development of CSP/STE technologies.

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[22] www.eu-solaris.eu

Annex I – R&I Activities

Updated CSP Implementation Plan: R&I Activities

Areas of activity	Defined R&I activities of current IP
1. Line-focus solar power plants technology	Activity 1.1: Component development, process innovation and cost optimization for molten salts systems Activity 1.2: Solar collector fields with silicone oil as HTF
2. Central Receiver power plants technology	Activity 2.1: Improvement and optimization of current central receiver molten-salt technology Activity 2.2: Innovative concepts, materials and components for central receiver molten-salt technology Activity 2.3: Solar tower with particle receiver technology
3. Reliable and cost-effective heat transfer medium and high-temp. thermal storage systems	Activity 3.1: Single molten salt thermocline Activity 3.2: Next generation of Thermal Energy Storage technologies
4. Turbo-machinery developed for specific conditions of solar thermal power plants	Activity 4.1: Development of expansion turbine technologies for advanced CSP power blocks Activity 4.2: Development of turbo-machinery for supercritical CO_2 cycles
5. Medium-and high temp. systems for industrial solar heat applications	Activity 5.1: Medium temperature systems for industrial solar heat applications Activity 5.2: High temperature solar treatment of minerals and metals
6. Thermochemical production of solar fuels and hydrogen	Activity 6.1: Liquid synthetic fuels from solar redox cycles Activity 6.2: Solar fuels from carbon neutral feedstock Activity 6.3: Solar particle receivers/reactors for solar fuels production
7. Cross-cutting issues	Activity 7.1: Digitalization of CSP plants for a more efficient monitoring, operation and maintenance Activity 7.2: Innovative coatings for CSP mirrors Activity 7.3: Reliable CSP, PV and other renewables integration Activity 7.4: Promoting the utilization of CSP with thermal storage to facilitate variable RE penetration in the electrical system

AREA OF ACTIVITY nº 1: LINE-FOCUS SOLAR POWER PLANTS TECHNOLOGY

R&I Activity 1.1: Component development, process innovation and cost optimization for molten salts systems

<table>
<tr><td colspan="4">Title:
Component development, process innovation and cost optimization for molten salt systems</td></tr>
<tr><td colspan="2">Previous related research activities:
- CSPEraNet EuroPatMoS,
- MATS,
- MS-Opera,
- MS-Trough,
- Partanna (Italian commercial project),
- Stromboli (Italian commercial project)
- INIESC (Portugal + ERDF 2017-2021)</td><td colspan="2">Achievements since 2017:
- MS technology demonstration at Evora Molten Salt platform
- Technology demonstration at MATS plant in Egypt (TRL8)
- Commercial tube receivers tested and validated at the ENEA’s PCS experimental platform in relevant conditions
- Partanna commercial plant (5 MWe, 12 hours’ thermal storage) installed in Sicily in 2020
- More suppliers able to deliver MS components
- Better understanding of critical cost reduction topics
- Better understanding of critical topics for drainage and filling</td></tr>
<tr><td colspan="2">Targets:
- Cost reduction by improved and tested MS components: collectors, solar field construction and operation procedures
- Development of new generation of CSP/STE technology
- Cost reduction in low sun periods</td><td colspan="2">Monitoring mechanism:
- Number of suppliers able to deliver reliable products
- Established test facilities for different size of components
- Cost reduction of typical components like MS valves or pumps, MS solar field
- Number of operating hours in nominal conditions
- Reduced operation costs of MS solar field
- Standards on MS plant operation procedures</td></tr>
<tr><td colspan="4">Description:
While normal operation of a Molten Salt (MS) parabolic trough or linear Fresnel loop has a large similarity with established oil-based systems, significantly different conditions are found during filling and in critical situations due to MS’ physical state at ambient temperature. All molten salt mixtures used today have a melting point well above ambient temperature which imposes, especially, the risk of freezing. Special procedures are therefore needed for first filling, for maintenance induced draining, and under emergency situations like pipe rupture to avoid large damage and associated costs. The activity heads for building up a profound understanding of the underlying effects by means of detailed physical modelling, validation activities and testing in prototype scale. It is considered as important to compile the findings in best practice guidelines available to industry. Cyber-physical testing capacities can support the costly testing activities by intelligently combining physical and simulation parts.
Demonstration activities for molten salt in line focusing systems have shown that solar field cost reductions might arise from, e.g. quality assurance procedures rendering cost-improved and faster solar field construction, cheaper manufacturing technologies and components or adoption of alternative “non-electrical” hydraulic loop pre-heating technologies for filling operations, amongst others. Besides, the still limited number of component suppliers currently also represents a cost factor. Valves or pumps are typical examples where costs for MS equipment is significantly higher when compared to components for water or oil. The activity requires a close cooperation between R&D institutions, component suppliers, and certification instances to come up with quality but cost-efficient testing capacities easily accessible by component manufactures. Supporting analysis should focus on the requirements of MS components in the parabolic trough or linear Fresnel application thus setting up suitable design targets for the industry.</td></tr>
<tr><td colspan="4">TRL: From TRL 5 to TRL 8</td></tr>
<tr><td colspan="4">Total budget required: 15 M€</td></tr>
<tr><td colspan="3">Expected deliverables:
- Testing under real operating conditions
- Development of new approaches to CSP solar field cost reduction strategies
- Assessment of cost reduction impact</td><td>Timeline:
3-5 years</td></tr>
<tr><td>Party/Parties:</td><td colspan="2">Implementation instruments:
- Horizon Europe Programme</td><td>Indicative financing</td></tr>
</table>

Interested countries: Germany, Portugal, Spain, UK, Greece	- Clean Energy Transition Partnership - Possible grants from Research Promotion Foundation under the RESTART calls and other structural funds (Cyprus) - German Energy Research Framework Programme - Helmholtz Program on Renewables (Germany) - Support from CDTI to technological development and industrial innovation (Spain) - Support/grants from National and Regional funding Portugal2030/Alentejo2030 to R&D activities (Portugal) - Support/grants from MICINN to research activities (Spain) - Contributions from European CSP/STE companies - Italian Electric System Research Program (2022-2024) - Greek next R&D Framework Programme (2021-2027) (under preparation, expected to be published not before mid-2022) - In-kind contribution from research and partner organizations	contribution: N/A

R&I Activity 1.2: Solar collector fields with silicone oil as HTF

<table>
<tr><td colspan="2">Title:
Parabolic trough with silicone oil (PTC with SiHTF)</td></tr>
<tr><td>Previous related research activities:
SiHTF (Germany, 2012-2015), SITEF (Solar ERA-Net, 2016-2017), EDITOR (Solar ERA-Net, 2016-2019), SIMON (Solar ERA-Net, 2017-2020), SING (Germany, 2020-2022), Si-Co (CSP ERA-Net, 2021-2023), Smart Solar Systems (Solar ERA-Net, 2021-2023), SolarPACES Guideline (SolarPACES, 2019-2022), International standard development (SolarPACES, 2021-2022)</td><td>Achievements since 2017:
- Loop-scale demonstration at 425°C of two HTF grades. Stress test passed (3000h at 450°C)
- Verification of silicone fluid durability and chemical stability during solar operation at 450°C
- Assessment of associated risks (SOTA comparison)
- Guideline for the use of SiHTF in line focusing CSP</td></tr>
<tr><td>Targets:
- Cost reduction
- Increased power plant reliability
- Application of new generation of CSP/STE technology in existing power plants</td><td>Monitoring mechanism:
- Power Purchase Agreements for new CSP plants in Europe
- Demonstration in 2-4 MW scale in existing installations
- Change of existing power plants to using SiHTF</td></tr>
<tr><td colspan="2">Description:
Silicone based heat transfer fluids enable higher operating temperatures in the solar field of parabolic trough plants; this applies to existing and future power plants. At the same time these fluids have significant advantages when it comes to Globally Harmonized Systems (GHS) labelling which is relevant when shipping, handling and in case of leakages compared to the actually used fluids in commercial plants (eutectic mixtures of BP/DPO). The expected operating temperature limit of silicone oil is up to 450°C, requiring a periodical HTF exchange rate. Thus, SiHTF allows more than 50°C higher temperatures compared to the state-of-the-art synthetic oil which is operated only at 393°C. This additional temperature spread between inlet and outlet leads to more cost-effective storages and more efficient energy conversion at the power block side. Combined with innovative large-scale collectors with high concentration factors and high optical and thermal efficiencies the use of silicone oil can lead to significant cost reduction of power production. The application of SiHTF in new power plants requires full demonstration of essential sub-components such as: high flux collectors, receivers, heat exchanger and steam generator in a pre-commercial scale with at least two complete loops. The application of SiHTF in existing power plants requires the full demonstration of the HTF changeover at an existing collector loop in a commercial power plant. The accompanying research actions should answer all open questions concerning performance and durability of all involved elements of the systems in both scenarios to reach bankability at the end of the project.</td></tr>
<tr><td colspan="2">TRL: From TRL 7 to TRL 8 (some components, like the steam generator, is still at TRL 6)</td></tr>
<tr><td colspan="2">Total budget required: 6 M€</td></tr>
<tr><td>Expected deliverables:</td><td>Timeline:
3-5 years</td></tr>
</table>

<table>
<tr><td colspan="2">- Operation of at least one existing parabolic trough collector loop, replacing the state-of-the-art HTF with SiHTF, increasing the operation temperature to the given limits, continuous operation (480 h) to demonstrate durability
- Analysis of the hydrogen formation and degradation products
- Demonstration of SiHTF for new CSP power plants: construction of at least two loops of full-scale parabolic trough collectors including oil/salt heat exchanger and steam generator, specially designed for the SiHTF technology assessment of thermal performance
- Optimization of (oil/salt, oil/steam) heat exchanger for increased temperatures up to 450°C, also under transient conditions (e.g. in combination with mobile molten salt loop)</td><td></td></tr>
<tr><td>Party/Parties:
Interested countries:
Germany, Spain, Denmark, Greece, Cyprus, Switzerland, Turkey</td><td>Implementation instruments:
- Horizon Europe Programme
- Clean Energy Transition Partnership
- Possible grants from Research Promotion Foundation under the RESTART calls and other structural funds (Cyprus, others)
- German Energy Research Framework Programme
- Helmholtz Program on Renewables (Germany)
- Support from CDTI to technological development and industrial innovation (Spain)
- Support/grants from MICINN to research activities (Spain)
- Contributions from European CSP/STE companies
- Greek next R&D Framework Programme (2021-2027)
- In-kind contribution from research and partner organizations</td><td>Indicative financing contribution:

N/A</td></tr>
</table>

AREA OF ACTIVITY nº 2: CENTRAL RECEIVER POWER PLANTS TECHNOLOGY

R&I Activity 2.1: Improvement and optimization of current central receiver molten-salt technology

<table>
<tr><td colspan="2">Title:
Improvement and optimization of current central receiver molten-salt technology</td></tr>
<tr><td>Previous related research activities:
- STAGE-STE (2014-2018),
- PHOTON (2017-2019),
- CAPTURE (2015-2020).
- MOSAIC (2016-2021),
- RAISELIFE (2016-2020),
- SOLWARIS (2018-2021),
- NEWSOL (EU 2017-2021)
- HPMS-II / SALSA (Germany, 2018-2023),
- STERN (Germany, 2020.2024)</td><td>Achievements since 2017:
- Improvement of receivers, salt pumps, heat tracing systems, steam generators, hot-salt tank, heliostats and atmospheric attenuation on-line measurement.
- Better understanding of critical design and O&M topics of this type of solar plant</td></tr>
<tr><td>Targets:
- Solar thermal electricity cost reduction through lower CAPEX and/or OPEX</td><td>Monitoring mechanism:
- Qualification of prototypes at proper scale
- Standards on molten-salt plant O&M procedures
- Testing new molten salt HTF in pilot plants</td></tr>
<tr><td colspan="2">Description:
This R&I Activity is concerned with a complete set of items aimed at improving the molten salt central receiver technology currently available, thus achieving a significant cost reduction in the short term because all the proposed activities can be developed within a period of 3-5 years after the starting date. The proposed actions would lead to improvements that could be implemented soon in commercial STE plants to increase their competitiveness. It also includes Artificial Intelligence and Smart CSP concepts to improve reliability, performance and flexibility while reducing cost, bringing digital technology to CSP Industry.</td></tr>
<tr><td colspan="2">TRL: Final TRL: prototypes evaluated at real working conditions</td></tr>
<tr><td colspan="2">Total budget required: 35 M€</td></tr>
<tr><td>Expected deliverables:
SOLAR FIELD: Reduce environmental impact, increase nominal performance of heliostats and heliostat field by 5% and assure these values along lifetime while reducing solar field cost by 25% through:
- Reducing heliostat costs (advanced mirrors, manufacturing/assembly procedures, etc.)
- Tailored solar field designs and heliostat sizes according to the needs (distance, position in the field, etc.)
- Procedures for quick/cheap (re)calibration of heliostats that guarantee reliability and performances over lifetime, together with self-powering and self-diagnosing
- Improving mirror reflectance (near-specular solar reflectance >94.5%), durability, service lifetime and reliability in environments with different corrosivity (e.g. mirror degradation <0.5 ppt/year in low corrosive desert environment).
RECEIVER: Improve performance and durability of receiver through:
- Improved metal tubes, manufacturing techniques, unconventional materials and coatings or surface treatments (>97% solar absorptance and degradation rates <0.5ppt/year up to 750°C)
- Higher average solar flux densities (>1 MW/m^2)
MOLTEN SALT SYSTEM: Increase performance and reduce cost and environmental impact of molten salt system by:
- Reducing the metal corrosion of all components (receiver, piping, pumps, weld joints…)
- Alloy or coating development to prevent the existence of chromium at the material's surface, or electrochemical removal of chromium from the molten salt to avoid health issues
- Assessment of stability, compatibility and corrosivity of new molten salts
O&M: Reduce OPEX and increase plant performance and safety through:</td><td>Timeline:
3-5 years</td></tr>
</table>

- Improved plant instrumentation and data management, to provide the operator with reliable on-line information on plant status (e.g., heliostat performance) and operating conditions (e.g., solar flux measurement, atmospheric attenuation) - Soiling reduction methods, cleaning methods and strategies for saving water and OPEX. - Development of predictive maintenance tools and procedures - Optimized O&M procedures/tools to reduce costs and auxiliary energy consumption - Development of safe O&M procedures and control strategies for emergency situations in order to avoid large damage of the receiver, piping and components - Strategies for safe/fast receiver pre-heating, and partial-load and full-load operation		
Party/Parties: Spain, Germany, Israel, Czech Republic, Denmark, Turkey Belgium, Cyprus, Italy, Portugal	Implementation instruments: - Horizon Europe Programme - Clean Energy Transition Partnership - National R&D funding programs - Contributions from European CSP/STE companies - In-kind contribution from research and partner organizations - Italian Electric System Research program (2022-2024)	Indicative financing contribution: N/A

R&I Activity 2.2: Innovative concepts, materials and components for central receiver molten-salt technology

Title: Innovative concepts, materials and components for central receiver molten-salt technology	
Previous related research activities: EUROSUNMED (2013-2017), PHOTON (2017-2019), CAPTURE (2015-2020), SOLWARIS (2018-2021), INNSOLAR (2016-2019), MOSAIC (2016-2021), HIFLEX (2018-2022), POLYPHEM (2018-2022)	Achievements since 2017: - Small plants using molten sodium as working fluid - Prototype of 300 kWth volumetric receiver coupled to a 50 kWe hot-air turbine
Targets: - Solar thermal electricity cost reduction - Flexible electricity generation and storage - Development of new generation of CSP/STE technology	Monitoring mechanism: - Qualification of prototypes - Demonstration at 500 kW scale - PPAs of new CSP/STE plants
Description: The energy transition to a sustainable and decarbonized model is urgent. Attending this urgency in a wise and clever way requires the analyses of the real needs at system level and the development of different concepts combining/integrating current and emerging technologies to meet these requirements. Flexible and economically competitive solutions must be developed to guarantee the competitiveness of CSP technology in the future energy system. Due to their higher working temperature and potential for cost reduction, central receiver plants are expected to increase their capacity installed significantly. However, the current central receiver technology, based on molten-salt receivers, has significant limitations and new concepts must be developed to achieve higher working temperatures. The solar-to-thermal and the thermal-to-electricity conversion efficiencies at CR plants correlate conversely when upscaling the power plant. While the solar-to-thermal energy conversion process (heliostat field and solar receiver) works best for small solar fields and low nominal power of the solar receiver, the conversion efficiency of the power cycle is best for high nominal powers. Therefore, also plant concepts economically competitive at small power range (< 20MWe) or multi-tower concepts, including hybridization with other renewable energies, must be investigated to get benefit of the high degree of dispatchability of central receiver plants and the low cost already achieved by wind farms and photovoltaic plants. However, the optimum integration of these technologies may require the implementation of electricity storage linked to the thermal energy storage unit of the CSP/STE plant.	
TRL: Goal: TRL 5-6	
Total budget required: 30 M€	
Expected deliverables: - New working fluids with thermal limit above 600ºC (ideally between 700°C and 1000°C). - New reliable solar receiver materials for temperatures adapted to the higher temperatures working fluids above	Timeline: 4-5 years

- Small-scale prototypes of highly flexible CSP/STE power plant concepts (and hybrid solutions with, e.g. power-to-heat-to-power integration, or alternative storage options) that allow adaptive power generation according to the needs of the electricity grid, also including electricity storage. - Small-scale multi-focus tower systems with optimized use of the heliostat field at different relative sun positions. - Modular small-scale beam down systems with improved optical efficiency/cost ratio for simplified process integration. - Small-scale (0,3- 10 MWth) prototypes of cost-effective, durable, flexible and/or easy to integrate/hybridize with other technologies solar receivers with working temperatures in the range 700°C - 1000°C and higher solar fluxes (> $1MW/m^2$). - Small-scale complete power cycles (<200 kWe) or components highly cost-effective and suitable for centralized and decentralized power generation, that: ○ have potential scaling up for demonstration at higher power ranges (< 20MWe) ○ have maximum cycle temperatures below 900°C (ideally between 700 and 1000°C) - Small-scale (600 kWh_{th}) prototypes of cost-effective thermal energy storage technology that is compatible with high operating temperatures (ideally between 700 and 1000°C) and the applied working fluid.		
Party/Parties: Spain, Germany, Israel, Czech Republic, Denmark, Turkey Belgium, Cyprus, Italy, France, Portugal	Implementation instruments: - Horizon Europe Programme - Clean Energy Transition Partnership - National R&D funding programs - Contributions from European CSP/STE companies - In-kind contribution from research and partner organizations	Indicative financing contribution: N/A

R&I Activity 2.3: Solar tower with particle receiver technology

Title: Solar tower with particle receiver technology	
Previous related research activities: - FP7 CSP2 (2011-2015), - H2020 Next-CSP (2016-2021) - Italian national projects: PON SOLTESS and PON BIOVALUE - EU-HIFLEX - US-DoE G3P3 - D-KostPar, CentRec Demonstration	Achievements since 2017: - Fluidized bed solar receiver ○ Prototype-scale loop testing (~1 MW_{th}) ○ Scaling-up design at 150 MW_e ○ Cost assessment for a peaker plant - Rotary kiln solar receiver ○ Concept demonstration reached 965°C ○ Erection of first small demonstration system underway (HIFLEX)
Targets: - Cost reduction - Heat storage and high efficiency cycle integration - Development of new generation of CSP/STE technology - high flexibility: use for process heat and power production up to 1000 °C	Monitoring mechanism: - Demonstration at 5 MW scale - Validation of new components and control systems
Description: Ceramic particles used as heat transfer medium and storage material offer the capability to reach high operation temperature (600°C – 1000°C). This temperature range is favourable to the integration of advanced conversion cycles with circa 50% efficiency and for efficient use of thermal storage. Particles are environmentally harmless and promise a significant reduction of storage cost, which makes them also attractive for power-to-heat-to-power applications. Particle technology was also recently selected in the US-DoE Gen3 program as the most promising approach for the demonstration of a full system as next step. Modular solar tower (multi-tower) concepts promise further cost reduction but require the use of low-cost autonomous heat transportation systems to transfer the heat to the user (power block, process heat application).	

<table>
<tr><td colspan="3">Hybrid CPV-CST receiver options are also considered attractive, enabling to use part of the radiation (especially the usually lost spillage radiation around the receiver) for low-cost direct electricity generation with CPV cells installed in certain locations of the receiver.
This breakthrough innovation involves new technologies that differ strongly from standard liquid-based solar power plant. They are, in particular, the solar receiver, the heat storage, the particle-to-working fluid heat exchanger and the particle circulation and conveying. The development of these specific components must be addressed as single systems and in complete loops that integrate all the functions. Moreover, high quality heliostat fields are necessary to operate high temperature solar receivers. Many solar receiver technology options are open in particle CSP, for example, concerning the solar receiver, falling curtain, rotary kiln, moving packed bed and fluidized bed are currently developed worldwide. Nevertheless, rotary kiln and fluidized bed technology have been developed at TRL5 in Europe.
The Activity aims at fully demonstrating all components such as: heliostats, receivers, particle storage, heat exchanger and hot particle conveying in a prototype and/or pre-commercial scale representing a module of a multi-tower system. The accompanying research actions should answer all open questions concerning performance, safety, environmental impact and durability of all involved elements of the system to reach bankability.</td></tr>
<tr><td colspan="3">TRL:
From TRL 5 to TRL 8</td></tr>
<tr><td colspan="3">Total budget required: 30 M€</td></tr>
<tr><td colspan="2">Expected deliverables:
- Construction and demonstration of solar particle system including up scaled and improved components (receiver, heat exchanger / steam generator, transport systems, storage, ...)
- Long term operation to identify durability issues, analysis of degradation effects
- Assessment of performance of the system and its subcomponents
- Demonstration of hybrid receiver configurations, combining PV and thermal receivers
- Update and development of international standards for the use of particles in CSP systems
- Integration of high efficiency conversion cycles
- Assessment of environmental and safety issues</td><td>Timeline:
3-7 years</td></tr>
<tr><td>Party/Parties:
Interested countries: France, Germany, Spain, Belgium, Italy, Turkey</td><td>Implementation instruments:
- Horizon Europe Programme
- Clean Energy Transition Partnership
- German Energy Research Framework Programme
- Helmholtz Program on Renewables (Germany)
- Support/grants from various national support programs
- In-kind contribution from research and partner organizations
- Regional funds
- Contributions from European CSP/STE companies</td><td>Indicative financing contribution:

N/A</td></tr>
</table>

AREA OF ACTIVITY Nº 3: RELIABLE AND COST EFFECTIVE MEDIUM AND HIGH TEMPERATURE THERMAL STORAGE SYSTEMS

R&I Activity 3.1: Single molten salt thermocline

Title: Single tank molten salt thermocline	
Previous related research activities: - MATS (EU 2011-2018) - NEWSOL (EU 2017-2021) - NEWCLINE (CSP Eranet 2021-2023) - MoBaCline (German Funding 2019-2022) - MS-Store (German Funding 2011-2019) - TESCONSOL EIT-KIC InnoEnergy project, 2011-2014) - H2020 - RESLAG - H2020 - ORC-PLUS - H2020 - IN-POWER - Italian Electric System Research Program (2019-2021)	Achievements since 2017: - Technology prototype demonstration at EMSP Portugal - TESIS store DLR Germany (4 MWh, 560°C) Technology demonstration at ENEA facilities - Technology demonstration in real scale at MATS plant (Egypt, ORC-PLUS Morocco) - Understanding of critical cost reduction topics - Assessment of filler materials - Assessment of tank designs (e.g., steel, concrete as replacement) - Cross-technology assessment parameters understood - Techno-economic analysis shows 5-10% LCOE reduction potential for thermocline filler - Critical design aspects identified and partly examined
Targets: - Development of new TES technology - Cost reduction of dispatchable power, LCOE - Cost reduction of TES CAPEX & OPEX - Enlarge TES duration beyond two tanks for 24/7 economically viable solar thermal baseload production - Modelling validation - Ratcheting issue deeper understanding - Integration with power/heat grid - HSM characterizations - Integration of additional PCM materials	Monitoring mechanism: - Enhanced performance of Thermocline TES technologies - Standardization of TES performance assessment - 50 MWh_{th} on-sun demonstration - Successful operation for >1 year - Workshop with potential CSP plant operators
Description: Besides its paramount importance for CSP competitiveness in the production of dispatchable power, the use of medium and high temperature TES technologies stands for an important energy system regulator alternative when the integration of different waste heat or renewable energy sources in envisaged. The single tank technology has several advantages compared to the state-of-the-art two-tank molten salt system. They include lower heat losses (about half the value of two-tank systems), lower footprint, no restriction of tank height by the salt pumps, and most importantly the potential of a significant CAPEX TES reduction. Among the different single tank concepts (moving barrier, natural stratification), the thermocline filler concept has the highest CAPEX reduction potential due to the replacement of molten salt by an inexpensive filler, with improved specific heat, in direct contact to molten salt. For its storage cost reduction potential, the use of thermocline systems is being demonstrated in different research projects and infrastructure facilities (see achievements above). Considering the potential performance impacts of storage media, aspect ratio, stratification strategies, charging/discharging strategies or construction materials in these systems, standardized testing procedures and assessment parameters are needed to enable cross-technology comparison of these solutions. The activity aims at the development of such testing procedures and assessment parameters on the basis of applied research on different existing systems and research infrastructures, paving the way for the further development of different cost-efficient technological solutions enabling a full on-site demonstration in a CSP plant as a next step. The accompanying research action is still necessary with the current TRL and should answer all open questions concerning the critical design aspects (e.g. filler compatibility, thermo-mechanical design, tank maintenance and repair) using the expertise of different research units. Performance and	

durability of all involved elements of the system is addressed with at least one-year operation within the project to reach bankability at the end of the project. The activity requires a close cooperation between R&D institutions, companies for supply and development (e.g., materials, components, TES technology) and CSP plant operators.		
TRL range: 5 to TRL 7		
Total budget required: 30 M€ (e.g., two on-site demo projects; IA or CSP Eranet)		
Expected deliverables: - On-site demonstration of the molten salt thermocline filler concept at a relevant scale of 50 MWh_{th} in a CSP plant		Timeline: 5 years
Party/Parties: Interested countries: Germany, Portugal, Spain, Italy	Implementation instruments: - Horizon Europe Programme - Clean Energy Transition Partnership - German Energy Research Framework Programme - Helmholtz Program on Renewables (Germany) - Support/grants from National and Regional funding Portugal2030/Alentejo2030 to R&D activities (Portugal) - Contributions from European CSP/STE companies - In-kind contribution from research and partner organizations	Indicative financing contribution: N/A

R&I Activity 3.2: Next generation of Thermal Energy Storage technologies

Title: Next generation of Thermal Energy Storage technologies	
Previous related research activities: - RESTRUCTURE (2011-2016), - TCS Power (2011-2015), - StoRRe (2012-2016), - PEGASUS (2016-2021), - SOCRATCES (2018-2021), - SoCaLTES (Portuguese funding 2019-2022) - CSP ERANET project “InnoSolPower” 2020-2023 - Next-CSP (2016-2021)	Achievements since 2017: - Lab- to pre-pilot scale demonstration, in certain cases under relevant conditions - Proof-of-concept validation of certain systems and key components - First complete design of storage system integration into next generation CSP plants (mainly power tower systems using air as HTF) - Preliminary cost estimations showing competitiveness of technology in certain cases - Guidelines for future development & identification of challenges to be tackled in some cases
Targets: - Cost reduction - Development of breakthrough thermal energy storage technologies - Demonstration of key aspects for integration in CSP plants	Monitoring mechanism: - Demonstration under relevant conditions and ≥300 kWh_{th} scale - Benchmarking with state-of-the-art sensible heat storage technologies
Description: The exploitation of reversible chemical reactions with high reaction enthalpy and temperatures in the range of 600-1000ºC can become the basis for the next generation, compact thermal energy storage systems, particularly for the case of point focusing systems (e.g. Solar Tower plants). Such thermochemical energy storage concepts can also offer the flexibility of longer term (e.g. seasonal) storage and in some cases even provide links with existing industrial processes of high importance. Prominent examples of such systems, already validated in the framework of past collaborative EU projects, include redox pairs, reactions based on cyclic hydration/dehydration or carbonation/decarbonation of suitable materials and thermochemical cycles based on sulphur as heat storage medium and/or future energy carrier. In addition to thermochemical storage, the topic of next-generation TES is open to different technologies. Examples of other promising TES technologies include phase change material storage (PCM) for solar process heat steam supply, (rock/gravel/structured/fluidized) bed storage systems, filler storage in combination with other fluids than molten salt (e.g. molten metal), TES with alternative molten salts other than Solar Salt (e.g. carbonates, chlorides), molten metal as heat transfer fluid (e.g. as primary loop for towers), solid particle TES (e.g. in cooperation with the Gen3 US development) or other high temperature thermal energy storage	

materials and concepts. Proposals are expected to address one of those systems and present a clear development pathway in the lifetime of the project, also addressing a roadmap to pre-commercialization in the framework of relevant suggested post-project activities. The methodologies of choice/definition of the key components of proposed technologies should ensure maximization of the durability and minimization of the use of critical, strategic, scarce or costly materials. Concepts in the framework of optimum use of resources and/or in line with circular economy principles and good practices are also encouraged (including an analysis of durability issues). The proposed technologies should clearly demonstrate compatibility with existing or future configurations of CSP plants, with emphasis on the potential of their coupling to high temperature/high efficiency power cycles (e.g. Air Brayton, supercritical CO_2) and relevant combined cycles. Proposals should contain a first convincing high-level design of such integration, defining important aspects to be validated in the framework of the lifecycle of the project. Such aspects should also be translated to relevant Key Performance Indicators (KPIs) and where applicable relevant quantitative targets, which will be used to monitor the progress and success of the project, must be defined.		
TRL: From TRL 4 to TRL 6. TRL may be also related to integration and validation of developed systems for at least 100 cycles of operation, or the key components only		
Total budget required: 15 M€ (e.g., three projects; RIA or CSP Eranet)		
Expected deliverables: - Construction and validation under relevant conditions (e.g. in an existing solar platform or relevant environment in laboratory) of a prototype system - Operation for at least 100 h and/or at least 100 cycles to identify durability & cycling (charge/discharge) issues - Assessment of performance of prototype energy system and its key components, subcomponents & peripherals - Analysis of solar energy storage charge/discharge profiles & optimum operating temperature under relevant conditions - Analysis of materials (heat storage medium, key construction materials) and definition of compatible heat transfer fluid(s)		Timeline: 3-5 years
Party/Parties: Interested countries: Greece, Germany, Spain, France, UK, ITALY, Portugal	Implementation instruments: - Horizon Europe Programme - Clean Energy Transition Partnership - German Energy Research Framework Programme - Greek next R&D Framework Programme (2021-2027) (under preparation, expected to be published not before mid-2022) - Helmholtz Program on Renewables (Germany) - Support from CDTI to technological development and industrial innovation (Spain) - Support/grants from MICINN to research activities (Spain) - Contributions from European CSP/STE companies - National R&D funding programs - In-kind contribution from research and partner organizations	Indicative financing contribution: N/A

AREA OF ACTIVITY Nº 4: TURBO-MACHINERY DEVELOPED FOR SPECIFIC CONDITIONS OF SOLAR THERMAL POWER PLANTS

R&I Activity 4.1: Development of expansion turbine technologies for advanced CSP power blocks

<table>
<tr><td colspan="2">Title:
Development of expansion turbine technologies for advanced CSP power blocks</td></tr>
<tr><td>Previous related research activities:
H2020-LCE-7-2017: New cycles & innovative power blocks for CSP plants</td><td>Achievements since 2017:
- Carbosola (German funded research program)
- Solarsco2ol (H2020 funded program GA 952953)
- Desolination (H2020 funded program GA 101022686)
- SCARABEUS (H2020 funded program GA 814985)
- Technology demonstration at Evora Molten Salt platform
- Cross-technology demonstration</td></tr>
<tr><td>Targets:
- Cost reduction
- Development of new generation of CSP/STE technology</td><td>Monitoring mechanism:
- Replacement of steam turbine power block
- Power cycle performance improvement</td></tr>
<tr><td colspan="2">Description:
The use of solar thermal energy for power production purposes might range from the multi-MW scale dedicated high temperature heat production in CSP Plants to kW scale low and medium temperature production combined with other sources (e.g. waste heat) for poly-generation purposes in Industry or isolated communities.
As of suitable power cycles, solar thermal driven applications have been sought for a wide range of thermodynamic cycles: steam Rankine, ORC, Brayton, Stirling, sCO_2, among others.
Considering not only the combination of storable solar thermal energy but also its combination with other possible heat sources and/or heat upgrade technologies, going as far as the Carnot Battery concept, the potential use of Turbo-machinery in different specific operation conditions is manifold and widens the possible use of solar thermal technologies in either CSP or CHP solutions.
The project should therefore pursue the expansion of turbines and technologies developed and optimized for the specifics of a modern and competitive CSP with improved efficiency, operational flexibility, and reduced first-time and service costs.
Development of expansion turbine technologies for advanced CSP power blocks
- Advanced sealing technologies – e.g. quasi-hermetic shaft seals
- Cost-effective and oxidation resistant alloys by extending the application of steel to higher temperatures (e.g. up to 650°C)
- Robust large last stage blades maximizing efficiency – e.g. improved air foil design, novel damping technologies
- Advanced concepts for optimized operational flexibility using state-of-the-art technologies (e.g. artificial intelligence, machine learning, digitalization)
Development of a supercritical steam turbine for CSP
- Development and holistic optimization of an advanced CSP cycle and power block featuring a steam turbine with elevated steam pressures (e.g. supercritical) and steam temperatures (≥600°C) in close cooperation between solar loop developers and turbine designer to optimize the dependencies between the power plant and the solar part such as storage system, receiver and heliostat field.
- Conceptual steam turbine design including advanced operational concepts
Based on existing R&D infrastructural assets, the activity promotes the development of a testing bench suitable for the operation of different turbomachinery under real solar operation conditions, enabling the demonstration of components and its emulation in different solar-driven applications.</td></tr>
<tr><td colspan="2">TRL:
- TRL3 (proof of concept of most promising technologies)
- TRL6 (technology potential demonstrated)
- TRL7 (technology demonstrated in system prototype)
- TRL8</td></tr>
<tr><td colspan="2">Total budget required: 9 M€</td></tr>
<tr><td>Expected deliverables:</td><td>Timeline:</td></tr>
</table>

- Most promising sealing technology demonstrated in system prototype - Oxidation resistant alloys validated in relevant environment for application ranges - Robust large last stage blade validated in relevant system prototype - Advanced concepts for optimized operational flexibility using state-of-the-art technologies (e.g. artificial intelligence, machine learning, digitalization) - Conceptual steam turbine design for an advanced CSP cycle with elevated main steam parameters (e.g. supercritical pressure and temperatures ≥600°C)		3-5 years
Party/Parties: Turbine industry, Solar loop developers	Implementation instruments: - Horizon Europe Programme - Clean Energy Transition Partnership - Contributions from European CSP/STE companies - In-kind contribution from research and partner organizations - German Energy Research Framework Programme - Helmholtz Program on Renewables (Germany) - Support/grants from National and Regional funding Portugal2030/Alentejo2030 to R&D activities (Portugal) - Contributions from European CSP/STE companies - In-kind contribution from research and partner organizations	Indicative financing contribution: N/A

R&I Activity 4.2: Development of turbo-machinery for supercritical CO_2 cycles

Title: Development of turbo-machinery for supercritical CO_2 cycles		
Previous related research activities: H2020-LCE-7-2017: New cycles & innovative power blocks for CSP plants	Achievements since 2017: - Carbosola (German funded research program) - Solarsco2ol (H2020 funded program GA 952953) - Desolination (H2020 funded program GA 101022686) - SCARABEUS (H2020 funded program GA 814985)	
Targets: - Cost reduction - Development of new generation of CSP/STE technology	Monitoring mechanism:	
Description: Expansion of turbines and technologies developed and optimized for the specifics of a modern and competitive CSP with improved efficiency, operational flexibility, and reduced first-time and service costs. **<u>Development of a supercritical CO_2 turbine for CSP</u>** - Development and holistic optimization of an advanced CSP cycle and power block supercritical CO_2 turbine as a working fluid, also considering the utilization of dopants, in close cooperation between solar loop developers and turbine designer to optimize the dependencies between the power plant and the solar part such as storage system, receiver, heliostat field. - Conceptual sCO_2 turbine design including advanced shaft train layout and operational concepts		
TRL: TRL6		
Total budget required: 1 M€		
Expected deliverables: Conceptual sCO_2 turbine design for an advanced CSP cycle		Timeline: (TRL6) 6 months
Party/Parties: Turbine industry, Solar loop developers	Implementation instruments: - Horizon Europe Programme - Clean Energy Transition Partnership - Contributions from European CSP/STE companies - In-kind contribution from research and partner organizations - Support from interested countries	Indicative financing contribution: N/A

AREA OF ACTIVITY nº 5: MEDIUM AND HIGH-TEMPERATURE SYSTEMS FOR INDUSTRIAL SOLAR HEAT APPLICATIONS

R&I Activity 5.1: Medium temperature systems for industrial solar heat applications

<table>
<tr><td colspan="2">Title:
Medium temperature systems for industrial solar heat applications (line focusing systems)</td></tr>
<tr><td>Previous related research activities:
SECASOL (2017-2020), ASTEP (2020.2024)
Modulus (Germany, 2021-2024)
INSHIP (EU, 2016-2020)
IEA SHC/SolarPACES Task Solar Process Heat
SHIP2FAIR (~2018–2023), Italian National Research Program PTR on the Electric System (2019-2021)
LIFESOLAR (Portuguese funding 2016-2020)</td><td>Achievements since 2017:
- Improved designs of linear Fresnel collectors
- Implementation of international working groups to contribute to the commercial development of this solar energy application
- Several installations for industrial heat in operation
- Concentrated collectors are getting part of IEA SHC Task 55 follow up on district heating</td></tr>
<tr><td>Targets:
- Thermal energy cost (T < 400°C) below 4 c€/kWh in Southern Europe and 7 c€/kWh in Northern Europe.
- New international standards defining qualification protocols for components and plant commissioning procedures
- Development of new generation technologies (collectors and components)
- New solar HTF</td><td>Monitoring mechanism:
- Total thermal power installed
- Commercial offers for new plants
- New experimental platforms for testing components, monitoring and maintenance procedures
- Evaluation and feasibility studies by research institutes
- Demonstration in 2 MW scale
- Validation in real scale possibility to use new HTF</td></tr>
<tr><td colspan="2">Description:
Decarbonization of the industrial sector is one of the priorities of the EU to achieve a carbon-neutral energy system. Since the industrial sector is responsible for 32% of the total World energy consumption and > 30% of the energy consumption in this sector is heat within the range 60–300°C, the development of solar systems to deliver this energy demand is a must for the decarbonization of the processes in industrial sector (e.g. drying, pasteurization, sterilization, steam production, distillation, bio chemical, cooking and many others). Some SHIP systems have been employed in the agri-food sector, but the SHIP systems are often relatively small. While the industry requires highly automated medium temperature systems with low O&M cost, to satisfy the several heat demand with several temperatures effectively. Some SHIP systems have been employed in the agri-food sector, but the SHIP systems are often relatively small. While the industry requires highly automated, medium temperature systems with low O&M cost, to satisfy the several heat demand with several temperatures for long term process effectively. To satisfy the industrial need the SHIP sector needs the development of highly autonomous solar fields to increase the amount of thermal energy delivered to the industrial process, to facilitate the use, and as well as to further reduce maintenance requirements. There is also an evident lack of international standards related to the monitoring and commissioning of industrial projects.
For instance, currently the implementation of concentrated collectors for process heat and industrial district heating in Europe is hindered by little knowledge on costs and on operation - at clients as well as at engineering bureaus/planners. Only few installations exist in Europe, and these have not been evaluated by independent entities. With publicly available documentation on the performance of the systems and their costs a significant progress is possible. A reduction of investment and operational costs is required by developing new components which are cost-effective and/or improve the performance. This can also be a full collector concept e.g. with reduced material consumption or using new solutions, such as high vacuum technologies or innovative materials and components. A higher degree of credibility by enhancing reliability and enlarging a cost data base is required.</td></tr>
</table>

<table>
<tr><td colspan="3">Projects, aiming the reduction of thermal energy cost for industrial process heat applications and for district heating below 4-7 c€/kWh, respectively in southern and northern Europe[23] (T < 400°C) by 2025, can/should include the following subjects:
- Best practices study that investigates the status quo and identifies problematic issues, along with potential solutions or approaches to address those issues. Lessons learned from the engineering, construction, commissioning, operations and maintenance of existing concentrated solar plants.
- Development of new components or new collector concepts that reduce costs in investment or operation and/or improve the performance of the solar field, the balance of plant and integration of heat.
- Highly autonomous solar fields to further reduce maintenance requirements and to increase the amount of thermal energy delivered to the industrial process.
- A row of demonstration projects incorporating best practices and new developments accompanied by a scientific evaluation of performance, reliability and durability. Development of international standards related to the monitoring and commissioning of industrial projects.
- Dissemination that addresses planners, potential customers and other stakeholders, especially those who are not familiar with the technology.
- Hybrid energy supply solutions that will include adapted and newly developed combinations of RES available for implementation in industrial processes and the combination with high temperature storage solutions.
- The radical adaptation of industrial processes and the integrated solar supply system by matching these to the concept of a solar reactor: by this, for example, the modular complexity of available solar integration concepts can be decreased, the control concept can be simplified, and the power demand for a supply system is reduced.</td></tr>
<tr><td colspan="3">TRL: From TRL 3 to TRL 7-8</td></tr>
<tr><td colspan="3">Total budget required: 25 M€</td></tr>
<tr><td colspan="2">Expected deliverables:
- Cheaper collector designs for line-focus and point-focus solar systems
- Specification of materials by typology of industrial sectors
- Standardized components for the balance of plant (interface between the solar field and the industrial process)
- Standardized components for installation in lightweight rooftops
- Feasibility tools to assess the suitability of any industrial sector with heat demand in the Concentrated Solar Heat range
- New international standards and guidelines defining qualification, monitoring and commissioning protocols
- Demonstration of the technology in commercial surrounding (process heat or district heating)
- Long term operation to identify operational and durability issues
- Demonstration of hybrid energy supply systems with optimized regulation and control concepts
- Pre-feasibility evaluation of replacing the existent process by re-engineered processes, which embed the solar technology (“Solar Reactors”).</td><td>Timeline:
3-5 years</td></tr>
<tr><td>Party/Parties:
Interested countries: Cyprus, Germany, Spain, UK, Portugal, Italy, Greece (R&D institutes,</td><td>Implementation instruments:
- Horizon Europe Programme
- Clean Energy Transition Partnership
- Possible grants from Research Promotion Foundation under the RESTART calls and other structural funds (Cyprus)
- German Energy Research Framework Programme
- Helmholtz Program on Renewables (Germany)</td><td>Indicative financing contribution:

N/A</td></tr>
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[23] Reference parameters for the estimation of the levelised cost of heat

- Location: Southern regions: above 1500 kWh/m^2/a / Northern regions: below 1100 kWh/m^2/a
- System lifetime: 25 years
- Costs: including technology and construction costs, not including external project costs, such as land, permitting, etc.

Industrial end users), France	- Support from CDTI to technological development and industrial innovation (Spain) - Support/grants from MICINN to research activities (Spain) - Contributions from European CST companies - In-kind contribution from research and partner organizations - Italian Electric System Research Program (2022-2024)	

R&I Activity 5.2: High temperature solar treatment of minerals and metals

Title: High temperature solar treatment of minerals and metals (point focusing systems)	
Previous related research activities: - SOLPART (2016-2020), - CaLyPSOL (2018-2021), - INSOLMIN (2017-2018), - SolarTwins (2019-2022) - Italian National Project: PON Biofeedstock	Achievements since 2017: - Lab- to pre-pilot scale demonstration under relevant conditions - Proof-of-concept validation of certain systems and key components - Demonstration of 15 kW lab-scale solar rotary kiln for the calcination of cement raw meal - On-sun demonstration of a 50 kW fluidized bed calcination of calcite. - Preliminary cost estimations showing the competitiveness of technology - Guidelines for future development & identification of challenges to be tackled
Targets: - Definition of process requirements and of a suitable reactor - Pilot-scale operation - Long-term continuous operation - Up-scaling and implementation in plant environment - Cost reduction	Monitoring mechanism: - Demonstration under relevant conditions and >100 kW_{th} scale - Benchmarking with conventional technologies
Description: The intensive energy industry, such as the cement and mineral industry, is responsible for a large amount of the C02 emissions. The calcination of limestone, in particular, is a big factor in the global anthropogenic CO_2 emissions, contributing to at least 8 % of the emissions associated with cement production. Solar heat can help the decarbonization of this sector. Concentrated solar thermal energy, in fact, can readily provide temperatures in the range of 600-1000°C in a renewable way. This temperature range is suitable for many high-temperature applications in the industry, such as the calcination of minerals, such as colemanite (around 600°C), phosphate ores (around 700°C) and limestone (around 900°C). About a third of the emissions in the calcination are caused by the utilized fuel, which could be replaced with CSTE in solar-rich regions. The remaining emissions are from the reaction itself, which can be sequestrated in a reactor, if an operation in a closed system is established. The big advantage of the CSTE system is its dispatchable operation, making it very suitable for operations in rural regions where connections to the energy network are more difficult. Moreover, some of the regions with highest solar radiation also coincide with locations of mineral mines, e.g. colemanite, copper, and their industrial treatments. The utilization of solar energy, in particular in the rural sites, would be a sustainable and economic alternative also promoting the creation of highly specialized technical sector. The approach can be extended to metallurgical processes either for preheating the ores or for melting the feedstock. The feedstock can be the ore from mines, by-products, or metals from recycling processes. In particular, processing of strategic metals should be addressed. Each of these applications requires an adaptation of the solar reactors based on the material and process characteristics. The optimisation and operation of such reactors at the lab- and pilot- scale will provide the base for their implementation at an industrial scale.	
TRL: from TRL 4 to TRL 6	
Total budget required: 10 M€ (about 4 projects from 2.5 M€ each)	
Expected deliverables: - Operating system at >100 kW scale	Timeline: 4 years

- Reliable operation for 8 h/day and several consecutive days - Product quality comparable or superior to conventional ones - Suitable implementation strategy in a solar field - Price competitive with conventional systems - Contributions towards standardized solutions		
Party/Parties: Interested countries: Germany, France, Italy, Spain, Argentina, Chile, Morocco, Portugal	Implementation instruments: - Horizon Europe Programme - Clean Energy Transition Partnership - ERA-NET - Bi-lateral programs between Europe and South America or Europe and Africa - German Energy Research Framework or Federal Ministry for Economic Affairs and Energy Germany) - National R&D funding programs	Indicative financing contribution: N/A

AREA OF ACTIVITY nº 6: THERMOCHEMICAL PRODUCTION OF SOLAR FUELS AND HYDROGEN

R&I Activity 6.1: Liquid Synthetic Fuels from solar Redox Cycles

<table>
<tr><td colspan="3">Title:
Liquid Synthetic Fuels from solar Redox Cycles</td></tr>
<tr><td colspan="2">Previous related research activities:
SolarJet (2011-2015); Sun2Liquid (2016-2020); ASTOR (2017-2020); H2CORK (Portuguese national funding 2017-2020)</td><td>Achievements since 2017:
Prototype demonstration in 50 kW scale on a solar tower</td></tr>
<tr><td colspan="2">Targets:
Improvement of solar-to-fuel efficiency
Realising continuous fuel production
Cost reduction</td><td>Monitoring mechanism:
Demonstration of entire production chain
Long term operation of demo production at solar tower facility</td></tr>
<tr><td colspan="3">Description:
Typical production pathways of synthetic fuels like kerosene, methanol or Fischer-Tropsch gasoline and diesel go through syngas which in turn can be produced from CO_2 and water by high temperature solar redox cycles. Thermochemical processes exhibit the potential to be more straightforward, more efficient, and less costly than competing processes. The most promising and advanced processes are those based on metal oxide cycles where prototypes of core components and core production chain elements have been developed and tested on solar towers. Those cycles are attractive as they involve only few chemical steps, leading to high reversibility and potentially high cycle efficiency. However, state-of-the-art ceria has proven to be unsuitable for liquid fuel production unless new structures possessing higher specific surface area and low optical thickness are developed, e.g. by using additive manufacturing technology. Reactor’s design needs also considerable improvement in view of low thermal shock resistance of ceria redox material as well as its low thermal conductivity and light colour.
Key steps of process intensification need to be implemented to reach the targets in terms of efficiency and cost to render such processes competitive. It is necessary to reuse a significant portion of the sensible high temperature heat in order to achieve process efficiencies that make the systems attractive for commercial use. Beyond that the handling of fluids needs to be improved, smart control procedures need to be incorporated and suitable 3-dimensional structuring of the redox materials are key to achieve high production rates and high reactor efficiencies through optimal heat and mass transfer in the reactor. The use of secondary concentrators needs to be envisaged to improve temperature uniformity throughout the bulk redox material. Potential pathways of process temperature reduction through hybrid thermo-electrochemical energy integration schemes need to be assessed. In addition, the reduction step yield can be improved through lowering the oxygen partial pressure, thereby increasing the overall efficiency. Reactors capable to operate under a vacuum, ought to be considered.</td></tr>
<tr><td colspan="3">TRL: from TRL 4 (start) to TRL 6 (target)</td></tr>
<tr><td colspan="3">Total budget required: 5 M€</td></tr>
<tr><td colspan="2">Expected deliverables:
- reaching solar to syngas efficiencies of higher than 10%
- ensuring fuel production cost < 3 €/liter (kerosene)
- successful on-sun operation of demonstrations in relevant scale (>50 kW) for at least 6-months operation time and implementing heat recovery solutions
- provide a technology with materials and all components scalable to multi-MW-scale
- Establishing thermochemical cycles as a viable and competitive production technology pillar for synthetic fuels</td><td>Timeline:
4 years</td></tr>
<tr><td>Party/Parties:
Spain, Germany, Switzerland, Italy, Greece, Portugal, France</td><td>Implementation instruments:
- Horizon Europe Programme
- Clean Energy Transition Partnership
- German Energy Research Framework Programme
- Helmholtz Program on Renewables (Germany)
- Support from CDTI to technological development and industrial innovation (Spain)
- Support/grants from MICINN to research activities (Spain)
- Regional and National funds (France)</td><td>Indicative financing contribution:
N.A.</td></tr>
</table>

	- Contributions from European chemical and petrochemical companies, gas providers, energy utilities - In-kind contribution from research and partner organizations	

R&I Activity 6.2: Solar fuels from carbon neutral feedstock's

Title: Solar fuels from carbon neutral feedstock's	
Previous related research activities: ASTERIX, CAESAR, (1990's), SOLASYS (1998-2002), SOLREF (2004-2010), SolMethCO2 (2010-2014), PEGASUS (2017-2021), INDIREF (2016-2019), INSHIP (BioHydrogen IAScheme, 2019-2020), INIESC (2017-2021), INIESC Évora CONNECT (2021-2023)	Achievements since 2017: - Development and construction of solar tower up to 100 kW peak - Demonstration of 22 kW indirectly air-heated reformer at 850°C in Synlight$^{©}$ solar-simulator facility - Demonstration of particle-and gas-based solar receivers to provide heat transfer fluids of temperatures ≥ 900ºC - Preliminary identification Alentejo's biomass potential for solar-driven processes - Development (and foregoing construction, 2022) of innovative beam-down solar tower for high concentration - Development of ceramic volumetric air receiver using ceria or SiSiC
Targets: - Solar-driven integration and utilization of carbon dioxide from flue gas, biogas or waste gas, combined with carbon looping schemes. - Development of new generation of CSP-driven solar fuels production technology coupled to industrially practiced liquid fuels production. - Development of new generation of solar tower/cavities for solar-driven processes - Wider (re)-use of biomass waste as feedstock - Industrial-scale demonstration plant targeting future market penetration - Development of cost-reduction and higher efficiency strategies for different types of operation.	Monitoring mechanism: - Prototype demonstration on a solar tower Demonstration under relevant conditions and ≥500 kW$_{th}$ scale. - Benchmarking vs. current non-carbon-neutral technologies and identification of possible business opportunities cases. - Production of H$_2$/syngas with different feedstock scenarios
Description: Renewable energy sources (RES) can reduce the dependency on fossil fuels that cause pollutant gas emission and climate change. However, along the way towards a completely "green" future energy system, "hybrid" transitional technologies are needed, coupling the innovative principles and characteristics of RES with the high-power density, ease of transportation/storage and long-term development that have established liquid hydrocarbon fuels (like e.g. gasoline, diesel, kerosene, or methanol) at a privileged position in our current energy mix. Solar thermochemical processes make use of concentrated solar radiation as the energy source of process heat to drive endothermic reactions. The current state-of-the-art shows that studies of biomass used as feedstock for syngas/hydrogen production have been developed in the past, based on well-known chemical reactions such as the "water gas shift" reaction and the Fischer-Tropsch process. Such technologies can as a first step be carbon-neutral instead of completely carbon-free, by e.g. employing carbon dioxide sequestrated from industrial processes or exploitable carbon-neutral streams like plastics (from valorisation), biogas or biomass. Such hydrocarbons' reforming/partial oxidation to syngas in particular, that is already industrially practiced at realistic operation temperatures, if in addition can be effectively driven by concentrated solar energy (CSE), can be rendered to a technically viable, pragmatic process option, attractive for large-scale implementation and demonstration. Most such CSE-driven hydrocarbons' processing approaches explored so far involved heating of the gaseous reactant mixture in an irradiated solar receiver/reformer. However, recent advances in solar receivers' capability of delivering heat transfer	

<table>
<tr><td colspan="3">fluids that can directly absorb solar irradiation (e.g. particle streams, gases), open a new path for such approaches. The proposed activity aims at demonstrating such novel efficient CSE-driven processing carbon-neutral syngas production schemes under on- and off-sun conditions and capability of direct coupling to both carbon dioxide-emitting as well as liquid hydrocarbons production industrial processes. As the standardization of such processes is far from being reached, the activity further seeks the combination of the latest development of solar optics/cavities and re-use of biomass waste, paving the way to industrial-scale projects for their feasibility demonstration, upon a clear definition, for specific reactions, of: a) the mass and energy balance of the chemical reaction involved; b) identification of most suitable feedstock´s targeting solar fuel production and/or chemicals; c) pre-dimensioning of the reactor and definition of pre- and post-treatments; d) identification of the mode of delivery of the radiative flux; e) the definition of the application's critical competitiveness parameters.</td></tr>
<tr><td colspan="3">TRL: From TRL 4 to TRL 6</td></tr>
<tr><td colspan="3">Total budget required: 10 M€</td></tr>
<tr><td colspan="2">Expected deliverables:
- Construction and demonstration on a solar tower facility of at least one solar reactor concept for the production of syngas suitable for downstream liquid fuels production
- Long term operation to identify materials durability and product gas composition stability issues
- Demonstration of off-sun (24/7) operation
- Concept, materials and components scalability to multi-MW-scale</td><td>Timeline:
3-5 years</td></tr>
<tr><td>Party/Parties:
Interested countries:
Germany, Spain, Portugal, Switzerland, Greece, France, UK</td><td>Implementation instruments:
- Horizon Europe Programme
- Clean Energy Transition Partnership
- Possible grants from Research Promotion Foundation under the RESTART calls and other structural funds (Cyprus)
- German Energy Research Framework Programme
- Greek next R&D Framework Programme (2021-2027) (under preparation, expected to be published not before mid-2022)
- Helmholtz Program on Renewables (Germany)
- Support/grants from National and Regional funding Portugal2030/Alentejo2030 to R&D activities (Portugal)
- Support from CDTI to technological development and industrial innovation (Spain)
- Support/grants from MICINN to research activities (Spain)
- Regional and National funds (France)
- Contributions from European CSP/STE companies
- In-kind contribution from research and partner organizations</td><td>Indicative financing contribution:

N/A</td></tr>
</table>

R&I Activity 6.3: Solar particle receivers/reactors for solar fuels production

<table>
<tr><td colspan="2">Title:
Solar particle receivers/reactors for solar fuels production</td></tr>
<tr><td>Previous related research activities:
PON SOLTESS (2010-2015), PON BIOFEEDSTOCK (2018-2021), PEGASUS (2017-2021), HESTHY (2017-2021)</td><td>Achievements since 2017:
- lab-scale hydrodynamic characterization
- lab scale high temperature characterization</td></tr>
<tr><td>Targets:
- Development of new technologies for solar fuels production
- Increase solar-to-fuel efficiency
- Reduction of solar fuels cost</td><td>Monitoring mechanism:
- Demonstration of the potential of reactor configuration</td></tr>
<tr><td colspan="2">Description:
Solar particle receivers/reactors are gaining extensive consideration in CSP applications, as solid particles can work as both HTF in the receiver, heat transfer and storage medium absorbing and withstanding radiative fluxes of several MWm^{-2} and, finally, as reactant in many thermochemical energy storage processes as solar fuels production. Typically, such processes involve gas–solid chemical reactions as are the case of the</td></tr>
</table>

<table>
<tr><td colspan="3">thermochemical cycles for H_2O and/or CO_2 splitting or of the solar-driven gasification or pyrolysis of biomasses. Among the particle receivers/reactors, fluidized beds as well as moved beds and rotary reactors were operated with success at lab-scale for the production of solar fuels/chemicals thanks to the excellent thermal properties, to the good interaction with solar radiation and the excellent response to the requirements of the thermochemical cycles.
A number of approaches are under investigation and under development to validate and demonstrate the use of particles to run different thermochemical processes for solar fuel production. There are concepts based on directly heating the active particles and other ones using the particles as a heat transfer medium. Thus, one of those concepts should form the basis of further developing a particle-based process for solar fuel production. It should make use of the specific advantages of such concepts, i.e. the potential for high reaction rates, for high heat recovery rates, for homogeneous reaction conditions, for effective mixing, for continuous operation and for the coupling to thermal storage units. Those characteristics render particle receiver/reactors very promising solar interface configurations for solar chemical applications. The main objective is to improve the solar-to-fuel efficiency of the thermochemical fuel production process by enhancing the absorption of concentrated radiation in the receiver/reactor and by pursuing the recovery of sensible heat of particle streams between high-temperature and low-temperature steps of the cycle. The final goal is the on-sun demonstration and systematic testing of the relevant solar particle technology in relevant scale.</td></tr>
<tr><td colspan="3">TRL: From TRL 2-3 to TRL 4</td></tr>
<tr><td colspan="3">Total budget required: 4-5 M€</td></tr>
<tr><td colspan="2">Expected deliverables:
- Construction of a particle-based reactor system for solar fuels production including all BoP units
- Long term reactor operation
- On-sun operation testing
- Analysis and optimization of solar-to-fuel efficiency
- Optimization and choice of advanced redox granular materials
- Development of novel reactor/receiver concepts in order to optimize yield and conversion factors</td><td>Timeline:
3-5 years</td></tr>
<tr><td>Party/Parties:
Interested countries: Italy, Germany, France, Austria, Portugal</td><td>Implementation instruments:
- Horizon Europe Programme
- Clean Energy Transition Partnership
- Regional and National funds (France)
- Support/grants from National and Regional funding Portugal2030/Alentejo2030 to R&D activities (Portugal)
- In-kind contribution from research and partner organizations</td><td>Indicative financing contribution:
N/A</td></tr>
</table>

AREA OF ACTIVITY nº 7: CROSS-CUTTING ISSUES

R&I Activity 7.1: Digitalization of CSP plants for a more efficient monitoring, operation and maintenance

<table>
<tr><td colspan="2">Title:
Digitalization of CST plants for a more efficient Monitoring, Operation and Maintenance.</td></tr>
<tr><td>Previous related research activities:
STAGE-STE (2014-2018), Solarpaces Task II, CAPTure (2015-2020), PHOTON (2017-2019), SOLWARIS (2018-2021), EuroPatMoS (2020-2023)</td><td>Achievements since 2017:
- Guidelines
- Different developments for solving particular issues up to TRL6</td></tr>
<tr><td>Targets:
- Reduce O&M Cost
- increase reliability and lifetime
- Boost performance along lifetime of the plant
- Tailored systems for plant monitoring.</td><td>Monitoring mechanism:
- Validation of systems in already existing plants
- Integration of certain developments in the new plants.
- Demonstrations at commercial scale</td></tr>
<tr><td colspan="2">Description:
In order for CST technology to be deployed on a massive scale, it must guarantee a high level of reliability that gives investors' confidence. In addition to capital cost, solar thermal power plants today still need to reduce operating and maintenance costs while increasing reliability and performance. This is the only way to gain the confidence of developers and investors in the technology and to ensure that CST plays the key role in the energy transition that it must play, increasing the flexibility of the energy system and boosting the share of renewables (including non-dispatchable ones such as PV and wind) thanks to its dispatchability and energy storage capacity.
Likewise, the plants must be much more automatic and easier to operate, taking advantage of the full potential of sensor technology, automation and IoT. As other industries have done, by "going digital," the CST can increase efficiency, reduce costs, optimize the use of resources (e.g., water) and develop customized applications for easy and reliable operation of the CSTP plants.
All systems shall be demonstrated at pre-commercial scale through their implementation in commercial CST plants.</td></tr>
<tr><td colspan="2">TRL:5-8</td></tr>
<tr><td colspan="2">Total budget required: 12 M€</td></tr>
<tr><td>Expected deliverables:
Development of the new generation of Characterization, Monitoring, Inspection, Maintenance and Control systems easy to integrate in existing and new CSP plants. Based on the experience gained in the last two decades, this should include the following developments, reaching a pre-commercial state:
- Cost-effective integration of sensors into components and systems to obtain collectors and heliostats with self-diagnostic, self-calibration and autonomous operation capabilities.
- On-line measurement of concentrated solar flux, receiver temperature and atmospheric attenuation for tower plants
- On-site diagnostics and optical characterization of collectors and heliostats.
- Field diagnosis of CCP receivers (leakage detection, ball joint leakages, mirror and glass cover breakage, H2 permeation, etc.)
- Advanced cleaning systems and anti-soiling treatments for mirrors
- Automatic and continuous monitoring of HTF degradation as well as improved treatments for HTF treatment and recovery.
- Introduce AI techniques for early fault diagnosis and preventive maintenance in addition to improved operation.
- Boost intelligence and integration of solar components for an improved O&M
- Optimal energy management strategies and control for integrating CSP systems in hybrid power plants (e.g., CSP and CPV).
- Advanced control for boosting the use of CSP-TES systems as flexible generation resource able to provide ancillary services to the power system.</td><td>Timeline:
3-5 years</td></tr>
</table>

- Digitalization of CSP plants integrated with storage systems (smart energy meters + communication devices + intelligent control and management tools a strategies) for improving solar generation dispatchability and participation to the electricity market. The developments should reach a pre-commercial state.		
Party/Parties: Spain, Germany, Denmark, Belgium, Cyprus, Israel, Turkey, Italy, Portugal, Greece, France	Implementation instruments: - Horizon Europe Programme - Clean Energy Transition Partnership - Contributions from European CSP/STE companies - Greek next R&D Framework Programme (2021-2027) (under preparation, expected to be published not before mid-2022) - In-kind contribution from research and partner organizations	Indicative financing contribution: N/A

R&I Activity 7.2: Innovative coatings for CSP mirrors

Title: Innovative coatings for CSP mirrors	
Previous related research activities: - CNR-PAS 2020-2021 “Flexible Photonics” - MAE Significant Bilateral Project between Italy and South Africa (2014-2017) “Plasmonics for a better efficiency of solar cells” - Centro Fermi PLANS project “Plasmonics and nanoantennas for solar cells” (2015-2017) - Industrial Research and Development project (2008 -2009) HCSC (High Concentration Solar Cell) – OPTOI Srl	Achievements since 2017: - Fabrication protocols of oxide-based Bragg structures and multilayers. - Experimental techniques to assess the optical, structural and morphologic parameters of the coatings and multilayer structures
Targets: - high reflectivity, high mechanical, thermal and chemical resistance and lifetime - mechanical flexibility - energy-efficiency processes	Monitoring mechanism: - Processes validation - Optical, structural mechanical assessment - Comparison with traditional CSP mirrors
Description: Rf-sputtering and sol-gel deposition techniques are employed to fabricate high reflectance coatings. Dielectric mirrors using glasses and glass-ceramics such as SiO_2/TiO_2 and SiO_2/HfO_2 are chosen as constituting materials because of their high reflectivity, high mechanical, and thermal and chemical resistance. To achieve targeted spectrally selective filters and high reflectivity in the main solar spectrum from visible to near infrared, our approach is to design and fabricate reflectance coatings using sub-wavelength photonic structures including multi-layered structures and one-dimensional photonic crystals. Besides the rigid structures, we plan to fabricate flexible glass reflectance coatings on mechanically flexible substrates to tailor spectral tunability. In particular, flexible glass-based reflective coatings on Schott AS 87 eco Thin Glass can work up to 590 °C and set a root for future roll-to-roll processing and curved-surface integration. Rf-sputtering deposition technique will be used to fabricate glass based SiO_2/TiO_2 and SiO_2/HfO_2 multilayer reflectors deposited on substrates of different shapes and nature. The designed fabrication protocol allows to tune the geometry of the layers and match the required optical features of the reflectors. Moreover, the fabrication procedure permits to fabricate glass multilayer structures with perfect adhesions also under sequent thermal treatment up to 800°C or also after sample processing like cutting or chemical cleaning. The possibility to move and rotate the substrates inside the deposition chamber allows depositing the multilayer structures also on curved structures. The fabrication protocol allows to deposit this class of reflectors also on flexible substrates keeping the optical, spectroscopic and morphological features also under mechanical deformation. The proposed structure can provide broad bandwidth of at least 300 nm tunable in the spectral range of 300-2500 nm with reflectivity above 95%. Furthermore, in the flexible coating the operative reflectance spectra can be further tuned thanks to the deformation of the structures. The available area of the samples is 10x5 cm but the deposition procedure is reproducible and allows to fabricate multiple samples with the same optical features.	

The energy-efficiency of production processes for reflective coatings is also an important issue. Besides, rf-sputtering, we employ sol-gel deposition for fabricating such reflective coatings on rigid and flexible substrates. The advantages of sol-gel are energy-efficient manufacturing process, low-cost, large-scale production, planar complex surfaces, and possible solution-processed flexible films. Sol-gel deposition techniques offer the possibility to fabricate glass-ceramics structures based on SiO2/HfO2 that allow the optical features of the glass together with the thermal and mechanical resistance assured by ceramics' materials. Anti-reflective coatings and multilayer glass ceramic structures will be fabricated by sol-gel route. The sol-gel derived reflectance coatings will be assessed and compared with similar rf-sputtered coatings in terms of working parameters such as spectral selective ranges, bandwidth operation, reflectivity, optical losses, mechanical and temperature resistance, mechanical flexibility, and total production cost. Optimization, characterization and validation of the operational response of the new coatings in accelerated aging conditions and natural exposure conditions in environments with different corrosivity will be also performed.		
TRL: From TRL 3/4 to TRL 6		
Total budget required: 10 M€		
Expected deliverables: - New coatings on flexible substrates - Qualification of coatings for outdoor application in different environments.		Timeline: 5 years
Party/Parties: Portugal, Italy, France	Implementation instruments: - Horizon Europe Programme - Italian National Recovery Plan: The Green Revolution Mission and Ecological Transition - Portuguese national and regional funding to R&D activities - Contributions from European CSP/STE companies - In-kind contribution from research and partner organizations	Indicative financing contribution: N/A

R&I Activity 7.3: Reliable CSP, PV and other renewables integration

Title: Reliable CSP, PV and other renewables integration	
Previous related research activities:	Achievements since 2017: - CSP-PV hybrids considered as viable option for electricity production plants. - First units constructed and in preparation
Targets: - Cost reduction of electricity - Development of new generation of CSP/STE technology	Monitoring mechanism: - Number of case studies for demonstrators - Potential of fully reliable hybrids in Europe and neighbouring areas
Description: The combination of a CSP and PV plant is beneficial when reliable power production at low cost is required. Many studies and first plants follow this concept. The concept has limitations when it comes to periods of several days with low sunshine or strong seasonal variation in solar resource. In order to reach fully reliable electricity production at the grid connection point CSP-PV units will be accomplished by backup energy sources. Such a full hybrid can deliver electricity 24/7 around the year. Renewable energy resources are the preferred backup option although efficient utilization of fossils fuels might be suitable as mid-term solution. Adding this third element to the hybrid plant, the optimization gets more complex since local availability of backup energy resources enters the field. Produced electricity can either be used in the grid or in large industrial plants with significant electricity and/or heat demand. The production of renewable hydrogen could be one of these customers (e.g. energy for electrolysers that required steam and electricity). The activity heads for the general investigation of the reliable hybrid system in general, providing tools and input data for analysis. Geographical solar resource data must be coupled with backup energy potentials to define high potential regions within Europe and neighbouring countries. The activity should head for preparing demonstration plants by defining case studies for different regions and setups in Europe. Due to the higher operating temperature, solar tower plants are most favourable for reaching high backup energy conversion efficiencies. Other technologies like parabolic trough with elevate temperature might be attractive, too. The objective of the activity in the tower plants sections is dedicated to techno-economic	

optimization of reliable hybrids and the preparation of case studies. The activity should be accomplished by system analysis showing the upcoming requirements and resources for such reliable power units (including LCA).		
TRL: From TRL 7 to TRL 8 (some components, like the optimized large-scale PT collector, are still at TRL 6)		
Total budget required: 10 M€		
Expected deliverables: - Techno-economic study on suitable technology options including costs of electricity and sustainability issues. - Case Studies for at least 4 configurations that can serve as template - At least two large scale demonstration projects prepared including all elementary engineering documents as basis for decision on implementation - Design tools for fully hybrid plants available in the market		Timeline: 3-5 years
Party/Parties: Interested countries: Germany, Spain, Greece, France (R&D institutes, Industrial end users), Portugal	Implementation instruments: - Horizon Europe Programme - Clean Energy Transition Partnership - Possible grants from Research Promotion Foundation under the RESTART calls and other structural funds (Cyprus) - German Energy Research Framework Programme - Helmholtz Program on Renewables (Germany) - Support from CDTI to technological development and industrial innovation (Spain)Support/grants from National and Regional funding Portugal2030/Alentejo2030 to R&D activities (Portugal) - Support/grants from MICINN to research activities (Spain) - Contributions from European CSP/STE companies - Greek next R&D Framework Programme (2021-2027) (under preparation, expected to be published not before mid-2022) - Regional funds (France) - In-kind contribution from research and partner organizations	Indicative financing contribution: N/A

R&I Activity 7.4: Promoting the utilization of CSP with Thermal Storage to facilitate variable RE penetration in the electrical system

Title: Promoting the utilization of CSP with Thermal Storage to facilitate variable RE penetration in the electrical system	
Main recent achievements. Since the first commercial developments in the 80s, Concentrated Solar Power (CSP) has evolved substantially. The main recent achievements include: - Installed capacity adds close to 7 GW worldwide with a significant trend to include large storage in the newest plants. The last CSP plants that got finance include 12+ hours of storage at nominal power. - The integration of PV with CSP is already a reality. In Dubai there is a 700 MW CSP plant with 250 MW of PV; in Morocco there is an option to integrate PV into the storage system and the recent tenders in Chile and Spain allow for hybrid schemes. In US and China, new RE auctions provide value to energy storage and flexibility being hybrid CSP + variable RE the most feasible alternative at competitive costs. - CSP deployment represents a new paradigm for the electrical sector in which there can be 24/7 solar generation with the associated impact on a reduced need of fossil fuels as back-up. More than 80% of the projects worldwide include a significant European share in the design and project development. By mastering the storage and the hybridization techniques, European companies will keep the leadership of the technology in projects all around the globe.	
Targets: - To analyse the role of CSP in increasing the RE share while keeping final energy system cost low towards a decarbonized energy system based in a RE mix. - Keep the European scientific basis, technological leadership and global role in the area of CSP with Thermal Energy Storage, while creating evidence for policy making and energy planners	Monitoring mechanism: - Inventory of utility-scale thermal energy storage facilities available in EU - Inventory of conventional and renewable operating power plants in Europe

<table>
<tr><td colspan="2">- To achieve, at least, 50% of thermal energy storage share among new energy storage systems to be installed in Europe, as key element to facilitate 2030 energy transition goals
- To achieve, by 2030, a minimum CSP penetration rate of 5% in CSP into the final electricity mix of southern European countries
- To achieve a significant reduction, at European level, of fossil fuel power plants overcapacity replacing it by dispatchable renewable plants (especially CSP with TES)</td><td>- Inventory of policies, regulations and auctions expressly including CSP with TES in short, mid and long-term plans</td></tr>
<tr><td colspan="3">Description:
Despite the degree of matureness of CSP & Thermal Storage and their benefits for the electrical system, both technologies are still rather unknown for the wide public and seldom considered by energy planners and policymakers. This lack of proper awareness is even more worrisome due to the relevance of European industry leadership on CSP technologies, with more than 80% of worldwide commercial installed power (close to 7 GW by end of 2021) being made by European companies. To revert this situation and considering the current urgency of energy storage for sustainable Electrical system development with a low level of curtailments, CSP need to further develop and demonstrate its operational capacity to provide firmness and robustness to the electrical system, facilitating the implementation of higher shares of variable RES
Validated tools and methodologies (financial, technical, planning, social etc.) are required to provide decision makers and energy planners with the best criteria to take the right decisions at any moment under any circumstances. This should include not only the technology cost but also, and much more important, the cost analysis of the electrical system as a whole (impact in the final cost for citizens and users), considering the final energy mix. Also, the intrinsic and distinguishable capabilities of CSP (dispatchable and secure clean RE) and the importance of the energy transition should not only be highlighted but also assure its arrival to all social levels, from policymakers to the general public.
To reach this goal, a highly multidisciplinary joint effort between energy system experts (operators, modellers, etc.), CSP experts, utilities, grid managers, communicators, etc., is essential to reach this project goals. A success factor will be the implementation of CSP models in at least three different energy system models. Coordinated studies on the values of CSP with the various models shall provide a profound a scientifically sound evaluation of CSP technology in the EU.</td></tr>
<tr><td colspan="3">Total budget required: **3-4 M€**</td></tr>
<tr><td colspan="2">Expected Outcomes/deliverables:
- Development of recognized, standardized tools and methodologies for a deeper, complete and harmonized understanding of the role and impact of CSP with Thermal storage technologies in high RES penetration scenarios.
- Implementation of CSP in at least three widely used energy system models used in the EU in order to reach a broad consideration of the CSP technology.
- Take into consideration of CSP as a real alternative to the phase-out of gas and coal for the full decarbonization of the power sector
- Provide a basis for the development of more informed policy, market support and financial frameworks
- Provide decision makers (policy makers and energy planners) with recognized standardized and validated tools and methodologies allowing for accurate assessment and the best criteria to take the right decisions at any moment under any circumstances.</td><td>Timeline:
3 years</td></tr>
<tr><td>Party/Parties:
Interested countries: Germany, Spain, Italy, Portugal</td><td>Implementation instruments:
- Horizon Europe Programme
- Clean Energy Transition Partnership
- National R&D funding programs
- Contributions from European CSP/STE companies
- In-kind contribution from research and partner organizations</td><td>Indicative financing contribution:

N/A</td></tr>
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