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SUNSON

Concentrated Solar energy storage at Ultra-high temperatures aNd Solid-state cONversion

## WP2 – Integration modelling and SUNSON tool development

# D2.1 – Technical demonstrator specifications and reference KPI benchmarking

Version 1

Document information

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## SUNSON Key Facts

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## SUNSON Consortium Partners

| N. | Partner | Acronym | Country |
|---|---|---|---|
| 1 | Universidad Politécnica Madrid - Instituto Energía Solar | UPM | ES |
| 2 | IDENER RESEARCH & DEVELOPMENT | IDE | ES |
| 3 | Norges Teknisk-Naturvitenskapelige Universitet | NTNU | NO |
| 4 | Plataforma Solar de Almería (PSA-CIEMAT) | PSA | ES |
| 5 | IonVac Process | IONV | IT |
| 6 | Holistic and ontological solutions for sustainability | HOLOSS | PT |



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# Executive Summary

This deliverable lists a set of technical specifications and key performing indicator (KPI) benchmarks of the SUNSON-Box prototype. The technical specifications will guide the design of the prototype within task T2.2 (*Conceptual process design of the SUNSON-Box*), whose results will be compiled in deliverable D2.2 (*Conceptual design and modelling for the overall SUNSON process*). The KPI benchmarking will be used not only to design the prototype, but also to evaluate the degree of success during the project development. All these parameters are listed in the tables below. The demonstrator will be designed with 4 solar apertures and 1 TPV generator. The total input solar power is greater than 20 kW (> 5 kW at each aperture) and the expected output electric power is 250 W. The storage capacity is > 10 kWh (thermal) and the overall efficiency is expected to be over 15%.

*Technical specifications of the demonstrator*

| Parameter | Variable | Value | Units |
|---|---|---|---|
| Number of solar apertures | $N_{apr}$ | 4 | - |
| Number of TPV generators | $N_{TPV}$ | 1 | - |
| Total input power at the solar apertures | $P_{sol}$ | > 20 | kW |
| Input solar power at each solar aperture | $P_{sol,apr}$ | > 5 | kW |
| Solar irradiance at each solar aperture | $I_{sol,apr}$ | > 100 | $W/cm^2$ |
| Area of each aperture | $A_{apr}$ | ~ 50 | $cm^2$ |
| Total PCM volume | $V_{PCM}$ | > 10 | L |
| TPV generator area | $A_{TPV}$ | > 100 | $cm^2$ |

*KPI benchmarking of the demonstrator.*

| Parameter | Variable | Value | Units |
|---|---|---|---|
| PCM temperature, melting point | $T_{PCM}$ | > 1200 | ºC |
| Stored latent heat in the PCM | L | > 1 | $kWh_{th}/L$ |
| Stored energy capacity | $E_{th}$ | > 10 | $kWh_{th}$ |
| TPV power density generation | $P_{d,TPV}$ | > 1 | $W_{el}/cm^2$ |
| Electrical output power capacity | $P_{el}$ | > 250 | $W_{el}$ |
| Thermal-to-electric conversion efficiency | $\eta_{TPV}$ | > 20* | % |
| Solar-to-thermal conversion efficiency | $\eta_{sol}$ | > 70* | % |
| Overall solar-to-electric conversion efficiency | $\eta_{tot}$ | > 15* | % |

** Without considering heat losses in the thermal insulation system, which are expected to be high due to the small dimensions of the demonstrator*

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# Abbreviations

CSP – Concentrated Solar Power

KPI – Key Performance Indicator

PCM – Phase Change Material

RES – Renewable Energy Sources

S2H2P – Solar to Heat to Power

SF – Solar Furnace

TPV – Thermophotovoltaic

WP – Work Package

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# 1 Introduction

## 1.1 Purpose of the document

This deliverable is intended to set the specific prototype specifications and key performance indicators that will be targeted and used to evaluate the performance of the system during modelling and experimental evaluation. It is linked to WP2, as a result of developing Task 2.1.

## 1.2 Objectives

This deliverable is aligned to the following specific objectives of the project:

- **Specific objective 1:** Design and development of a S2H2P (Solar to Heat to Power) prototype as feasibility and scientific proof of a novel power generation technology from solar radiation.
- **Specific objective 2:** Design and development of a suitable thermal storage system based on PCM (Phase Change Material) to be integrated into the SUNSON-Box.
- **Specific objective 3:** Flagship demonstration of a breakthrough and compact system (the SUNSON-BOX) integrating RES (Renewable Energy Sources) for power generation based on CSP (Concentrated Solar Power), PCM-storage and TPV (Thermophotovoltaic) conversion.

# 2 Demonstrator specifications and reference KPI benchmarking

## 2.1 Technical demonstrator specifications

The demonstrator specifications were already described in the proposal and are listed in Table 1 with additional and more detailed information.

The system will be designed with 4 sunlight absorber apertures and 1 TPV generator. The solar input power of the system is limited to the available SF (solar furnace) at PSA-CIEMAT. Despite the nominal power of the SF-60 furnace being 60 kW, the system will be designed for an input power of only about 20 $kW_{th}$. This decision has been taken because the maximum solar power is not always available (dependent on weather conditions), and the experiments may require a modification of the power level to allow for some flexibility of the size of the focal spot at the entry apertures of the system.

Additionally, the system will include 4 secondary concentrators, focusing sunlight at 4 different apertures. Therefore, the maximum sunlight power entering each secondary optics will be about 5 $kW_{th}$. In order to achieve a good solar-to-thermal conversion efficiency (detailed in section 2.2), the solar irradiance at the aperture should achieve at least 100 $W/cm^2$, which is equivalent to a sunlight concentration factor of 1000 suns. This means that each solar aperture will have an area in the range of 50 $cm^2$. Higher concentration factors can be reached by increasing the total input power.

Finally, in order to reach the required energy storage capacity and electric output power levels (detailed in section 2.2), the total PCM volume will be over 10 liters and the TPV generator area will be over 100 $cm^2$.

*Table 1. Demonstrator specifications*

| Parameter | Variable | Value | Units |
|---|---|---|---|
| Number of solar apertures | $N_{apr}$ | 4 | - |
| Number of TPV generators | $N_{TPV}$ | 1 | - |
| Total input power at the solar apertures | $P_{sol}$ | > 20 | kW |
| Input solar power at each solar aperture | $P_{sol,apr}$ | > 5 | kW |
| Solar irradiance at each solar aperture | $I_{sol,apr}$ | > 100 | $W/cm^2$ |
| Area of each aperture | $A_{apr}$ | ~ 50 | $cm^2$ |
| Total PCM volume | $V_{PCM}$ | > 10 | L |
| TPV generator area | $A_{TPV}$ | > 100 | $cm^2$ |

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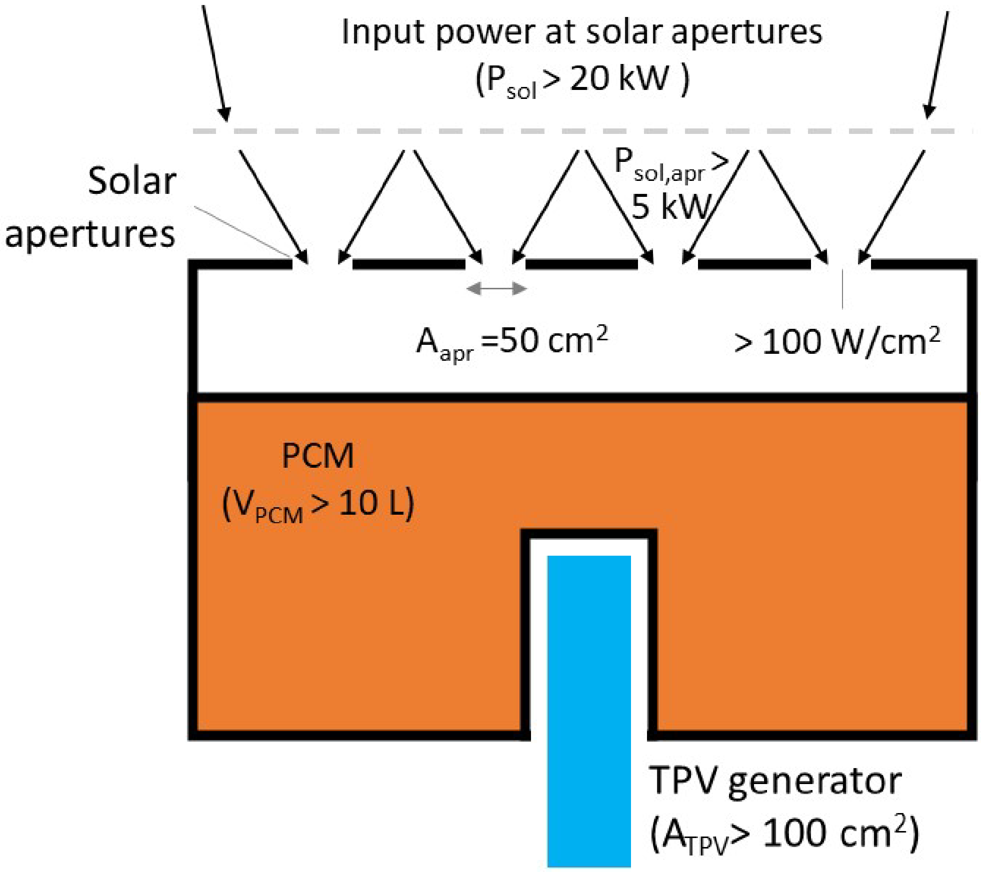


*Figure 1. SUNSON-BOX Concept Diagram indicating the specifications in Table 1.*

## 2.2 KPI benchmarking

The demonstrator is designed with the specifications listed in Table 1 and shown in Figure 1 in order to fulfill some key performing indicators (KPI). The targeted values for the most relevant KPIs are indicated in Table 2.

As specified in the proposal, the PCM melting temperature must be over 1200°C and the latent heat of the PCM should enable storing more than 1 $kWh_{th}$/L. This means that the complete demonstrator should have a storage capacity of at least 10 $kWh_{th}$. Moreover, the system is expected to produce an output power capacity of 250 $W_{el}$ with an overall solar-to-electric conversion efficiency over 15%.

It is important to note that all the efficiencies provided in this deliverable do not consider the thermal insulation losses. These losses are difficult to estimate at this early stage of the project and are expected to be large due to the relatively small size of the demonstrator. Because the duration of charge and discharge periods are determined by these losses, they will not be discussed in this deliverable.

The PCM melting temperature is an essential parameter that will determine the trade-off between solar-to-thermal and thermal-to-electric conversion efficiencies:

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- **High PCM temperature enables a high TPV thermal-to-electric conversion efficiency and TPV power density generation capacities over 1 W/cm$^2$.** Because the targeted output electric power is 250 $W_{el}$, the required TPV module area will vary depending on the achieved power density. If the PCM temperature is 1200ºC, the expected TPV power density will be around 1 W/cm$^2$, and the required TPV module area will be 250 cm$^2$. However, if the PCM melting temperature were 1500ºC, the TPV power density could reach over 3 W/cm$^2$ [1], and consequently, the required module area would be around 80 cm$^2$. Moreover, the thermal-to-electric conversion efficiency of TPV is expected to increase with the temperature. Reported efficiencies for individual cells range from 25 - 30 % [2]–[4] (at 1200ºC) to 40% [5] (at temperatures over 2000ºC). Due to the novel and challenging cell design, the targeted thermal-to-electric conversion efficiency is expected to be 20%.
- **High PCM temperature will also cause higher thermal radiation losses through the solar aperture.** In the simplest approach (e.g., neglecting sunlight reflection losses or other heat leakages), the solar-to-thermal conversion efficiency can be calculated as [6]–[8]

$$\eta_{sol} = (P_{in} - P_{back})/P_{in}$$

being $P_{in}$ the incident sunlight power and $P_{back}$ the thermal radiation emitted back through the aperture. Assuming that no spectrally selective filters are used at the aperture, the thermal radiation losses (in W/cm$^2$) can be calculated using the Stefan-Boltzmann equation ($A\varepsilon\sigma T^4$, being $A$ the aperture area, $\varepsilon$ is the effective emissivity of the absorber, $\sigma$ the Stefan-Boltzmann constant, and $T$ the effective absorber temperature). Additionally, assuming a black body aperture, a solar-to-thermal conversion efficiency over 70% can be attained at PCM temperatures of 1200ºC if the input solar irradiance at the aperture exceeds ~ 100 W/cm$^2$. Alternatively, the same solar-to-thermal conversion efficiency can be obtained at PCM temperatures of 1500ºC if the solar irradiance at the aperture exceeds ~ 200 W/cm$^2$. Therefore, reaching the KPI of 70% will require a higher concentration factor (near or above 2000 suns) if the PCM has a higher melting temperature (near or above 1500ºC).

*Table 2. KPI benchmarking of the demonstrator.*

| Parameter | Variable | Value | Units |
|---|---|---|---|
| PCM temperature, melting point | $T_{PCM}$ | > 1200 | ºC |
| Stored latent heat in the PCM | L | > 1 | $kWh_{th}/L$ |
| Stored energy capacity | $E_{th}$ | > 10 | $kWh_{th}$ |
| TPV power density generation | $P_{d,TPV}$ | > 1 | $W_{el}/cm^2$ |
| Electrical output power capacity | $P_{el}$ | > 250 | $W_{el}$ |
| Thermal-to-electric conversion efficiency | $\eta_{TPV}$ | > 20* | % |
| Solar-to-thermal conversion efficiency | $\eta_{sol}$ | > 70* | % |
| Overall solar-to-electric conversion efficiency | $\eta_{tot}$ | > 15* | % |

** Without considering heat losses in the thermal insulation system, which are expected to be high due to the small dimensions of the demonstrator*

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# 3 Conclusions

The technical demonstrator specifications and KPI benchmarks have been provided. These metrics will be used to start the design of the SUNSON-BOX demonstrator, which is performed during task T2.2 - *Conceptual process design of the SUNSON-Box*, whose results will be compiled in deliverable D2.2 - *Conceptual design and modelling for the overall SUNSON process*.

However, deviations from these numbers may be expected depending on the results of more accurate simulations conducted in WP2 (task T2.3 - *Integrated simulation of RES, storage and energy conversion*) and the results of the initial modelling and design tasks of WP3 and WP4 (tasks T3.1 and T4.1 respectively), being of critical relevance the heat losses in the thermal insulation system, which will be evaluated and minimised in the future.

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