Ref. Ares(2022)6064023 - 01/09/2022

POLYPHEM
THE FUTURE OF SMALL-SCALE CSP PLANTS

# POLYPHEM

Small-Scale Solar Thermal Combined Cycle

# D5.1 Manufacturing / Installation of the thermal storage

Date of delivery 01/09/2022

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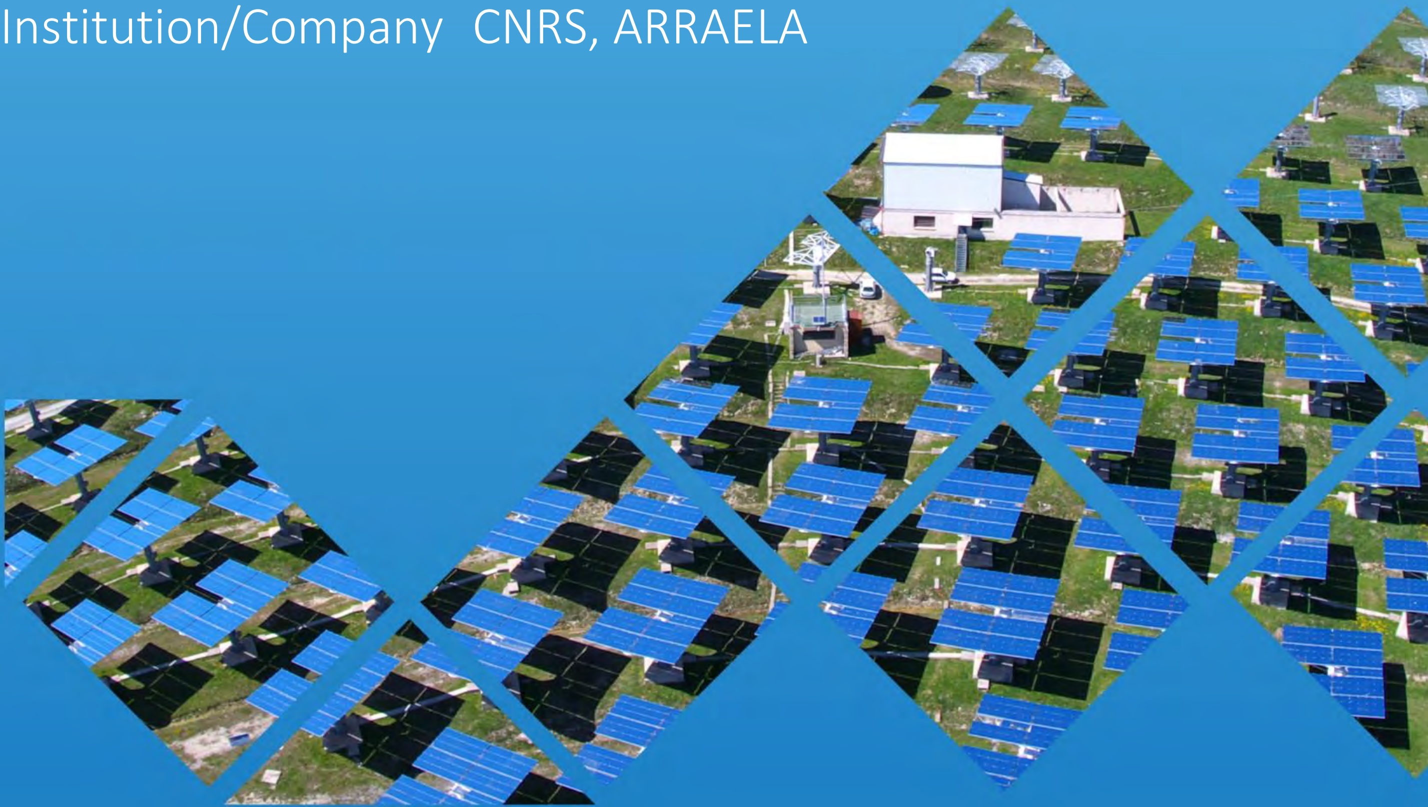
Institution/Company CNRS, ARRAELA



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764048.

## *Document tracks*

| **Identification** | **POLYPHEM_D5.1_Manufacturing&Installation of TES** |
|---|---|
| **TITLE OF DELIVERABLE** | **Manufacturing/installation of the thermal storage** |
| **Author(s)** | Alain Ferriere, Juan-Manuel Carruncho |
| **Reviewers(s)** | Lauriane Gonzalez |
| **Related Work Package (s)** | WP5: Manufacturing and installation of the prototype plant |
| **Beneficiary responsible of delivery** | ARRAELA |
| **Due date of delivery** | 28/02/2022 |
| **Actual date of submission/revision** | 01/09/2022 |
| **Number of pages** | **15** |
| **SUMMARY** | *This document is the deliverable D5.1 of the project POLYPHEM. It is planned in the framework of the Work Package 5 (Manufacturing and installation of the prototype plant).*<br>*The deliverable D5.1 is a demonstrator. It shows that the thermal energy storage (TES) tank is erected on the site of the solar tower facility THEMIS (France) as part of the prototype plant. The TES tank is made of concrete for the basement and for the wall. The filler bed consists of stacks of concrete bricks arranged in a compact pattern. ARRAELA designed the concrete material and erected the tank on site. CIEMAT supplied the measurement instruments and CNRS was in charge of the civil works, the implementation of the filler bed and the instrumentation.* |
| **Dissemination level** | PU |
| **Repository** | https://dms.polyphem-project.eu |

## *Document History and Validation*

| Date | Name | Comments |
|---|---|---|
| **28/08/2022** | Alain Ferriere | Creation |
| **29/08/2022** | Lauriane Gonzalez | Review 1 |
| **30/08/2022** | Alain Ferriere | Final |

## *Background: about the POLYPHEM project*

| **Full title** | **Small-Scale Solar Thermal Combined-Cycle** |
|---|---|
| **Acronym** | **POLYPHEM** |
| **Call identifier** | H2020 LCE-07-2017-RES-RIA-TwoStage |
| **Instrument** | Research and Innovation Action (RIA) |
| **Grant Agreement N°** | 764048 |
| **Starting Date** | 01/04/2018 |
| **Duration** | 48 months |
| **Website** | https://www.polyphem-project.eu |
| **Keywords** | Renewable electricity; Energy collection, conversion and storage; Renewable energy |
| **Additional keywords** | Concentrated solar power; Solar tower system; Combined cycle; Gas-turbine; Thermal energy storage; Organic Rankine cycle; Process control |
| **Beneficiaries** | CNRS, CEA, CIEMAT, Arraela S.L., Fraunhofer ISE, Kaefer Isoliertechnik, Orcan Energy, Euronovia, Aalborg CSP |

The POLYPHEM project is a research and innovation action funded by the European Union's H2020 program. It is implemented by a European consortium of 4 research centres and 5 industrial partners. The aim is to increase the flexibility and improve the performance of small solar tower power plants. The concept of POLYPHEM consists in implementing a combined cycle formed by a solarized micro gas-turbine and a Rankine organic cycle machine, with an integrated thermal storage device between the two cycles. The need for cooling is minimal.

Developed from a patented technology by CNRS and CEA, the pressurized air solar receiver is integrated in the micro-turbine cycle. The thermal efficiency targeted for the receiver is 80% with a cost of 400 €/kW. The innovative thermal storage uses a thermal oil and a single thermocline tank with a technical concrete filler material.

The main expected impact of this project is to enhance the competitiveness of low-carbon energy production systems through the technology developed. The expected progress is a better fitting of electricity generation to variable local needs, an overall conversion efficiency of solar energy into electricity of 18% for an investment cost of less than 5 €/W and a low environmental impact. By 2030, the cost of electricity production targeted by the POLYPHEM technology is 165 €/MWh for an annual direct normal irradiation of 2600 kWh/m$^2$/year (North Africa and Middle East) and 209 €/MWh under 2050 kWh/m$^2$/year (Southern Europe). In addition to decentralized power generation, other applications are considered for the deployment of this technology used in poly-generation: industrial heat production, solar heating and cooling, desalination of seawater or brackish water.

A prototype plant of 60 kW$_{el}$ with a thermal storage of 1300 kWh is designed, built and installed on the site of the experimental solar tower of Themis in Targasonne (France). The objective of the project is to validate the technical choices under test conditions representative of actual operating conditions.

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## *List of Acronyms and Abbreviations*

| Acronym/abbreviation | Meaning/full text |
|---|---|
| **CIEMAT** | Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas |
| **CNRS** | Centre National de la Recherche Scientifique |
| **HTF** | Heat Transfer Fluid |
| **ORC** | ‘Orcan Energy AG’ or ‘Organic Rankine Cycle’ |
| **PU** | Public |
| **RHX** | Recovery Heat Exchanger |
| **TC** | Thermocouple |
| **TES** | Thermal Energy Storage |
| **WP** | Work Package |

# 1. THERMAL ENERGY STORAGE SYSTEM

## 1.1 THERMAL STORAGE TANK

The thermal energy storage system is composed of a single tank which contains a porous filler bed. The heat transfer fluid (HTF) occupies the open porosity of the filler bed. A summary of the main physical parameters of the tank is presented in Table 1.

*Table 1: Summary of the main physical parameters of the storage tank*

| Description | Value | Unit |
|---|---|---|
| **TES TANK** | | |
| Cross-section area TES (dodecagonal) | 5.049502462 | $m^2$ |
| Number of stacks of filler bricks (1 stack=5 layers) | 4 | |
| Height of intermediate spacer between stacks of filler bricks | 0.03 | m |
| Height of filler zone | 2.09 | m |
| Volume of filler zone | 10.553 | $m^3$ |
| Porosity of filler zone (derived from Microsol-R) | 0.443 | |
| Volume of HTF in filler zone | 4.675 | $m^3$ |
| Height of bottom buffer zone (needed for diffusion of HTF) | 0.25 | m |
| Volume of bottom buffer zone | 1.262 | $m^3$ |
| Height of top buffer zone (needed for diffusion of HTF) | 0.25 | m |
| Volume of top buffer zone | 1.262 | $m^3$ |
| **OIL PIPES IN CIRCUIT: Tubes NF A 49-211 DN25 (1")** | | |
| Inner diameter of pipes | 27.3 | mm |
| Volume of fluid per length unit | 0.585 | l/m |
| Estimated total length of circuits | 435 | m |
| Estimated volume of HTF in circuits | 0.255 | $m^3$ |
| **OTHER COMPONENTS OF THE OIL CIRCUIT** | | |
| Volume of HTF in RHX (data Aalborg) | 0.11 | $m^3$ |
| Volume of HTF in ORC (data Orcan) | 0.035 | $m^3$ |
| Total volume of HTF outside of TES (in circuits + other components) | 0.400 | $m^3$ |
| **SUMMARY** | | |
| Total volume of HTF in operation @0°C (after filling) | 7.600 | $m^3$ |
| Density HTF @0°C | 1059 | $kg/m^3$ |
| Total mass of HTF in operation | 8048 | kg |
| Density HTF @350°C | 799 | $kg/m^3$ |
| Total volume of HTF in operation @350°C | 10.073 | $m^3$ |
| Max. volume for thermal expansion of HTF (from 0°C to 350°C) | 2.47 | $m^3$ |
| Height needed for thermal expansion of HTF in TES | 0.49 | m |
| Height of additional volume of air above HTF in TES tank | 0.15 | m |
| Total height of tank (inside) | 3.23 | m |

## 1.2 Thermal storage capacity

The thermal storage capacity is assessed assuming that the "cold" temperature of the storage is 110°C (returned back from the ORC after cooling) and the "hot" temperature is 330°C (heated up by the hot air in the RHX).

According to this assumption, the thermal storage capacity is 2482 kWh (8935 MJ). The detailed estimation is given in Table 2.

*Table 2: Thermal energy storage capacity*

| THERMAL ENERGY IN THE TANK | | |
|---|---|---|
| Temperature of HTF after preheating (TES fully discharged) | 110 | °C |
| Density of HTF | 977 | kg/m³ |
| Volume of HTF in the circuits + TES (after preheating) | 8.237 | m³ |
| Volume of HTF in the tank (after preheating) | 7.838 | m³ |
| Mass of HTF in TES tank | 7657,5 | kg |
| Temperature of HTF after heating (TES fully charged) | 330 | °C |
| Density of HTF | 814 | kg/m³ |
| Volume of HTF in the circuits + TES (after heating) | 9.887 | m³ |
| Volume of HTF in the tank (after heating) | 9.487 | m³ |
| **Mass of HTF in TES tank** | **7722** | **kg** |
| Intrinsic porosity of filler bricks | 0.274 | |
| Volume of concrete (filler bricks in TES tank) | 7.33187757 | m³ |
| Density of concrete | 3105 | kg/m³ |
| **Mass of filler in TES tank** | **22765** | **kg** |
| Specific heat of HTF and concrete (Heatek-RV) | | |
| Specific heat of HTF: CP0 | 1.5201 | kJ/kg.K |
| Specific heat of HTF: coefficient CP1 | 0.0031898 | kJ/kg.K/°C |
| Specific heat of filler: CP0 | 0.63 | kJ/kg.K |
| Specific heat of filler: coefficient CP1 | 0.00078571 | kJ/kg.K/°C |
| Specific heat of filler: coefficient CP2 | 0.00000429 | kJ/kg.K/°C² |
| **Thermal energy charged in the tank during full charge** | **8935** | **MJ** |

# 2. CONSTRUCTION OF THE TANK

## 2.1 TIME-TABLE OF THE CONSTRUCTION

The construction of the TES was executed from October 2020 to August 2022. The main steps of the construction are summarized in Table 3.

*Table 3: Main steps of the construction of the TES*

| Date | Action | Participants |
|---|---|---|
| **10/2020** | Manufacturing of filler bricks in Spain | ARRAELA |
| **10/2022** | Construction of insulation blocks for basement | ARRAELA |
| **25-29/10/2021** | Civil works at THEMIS site (France) for the foundations | CNRS |
| **01-05/11/2021** | Construction of bottom formwork and intermediate grids | ARRAELA |
| **08-12/11/2021** | 1st shipment of materials from Spain to France | ARRAELA - CNRS |
| **15-19/11/2021** | Construction of top cover of tank in Spain | ARRAELA |
| **29/11-03/12/2021** | Construction of reinforcements and preparation of other materials in Spain | ARRAELA |
| **13-17/12/2021** | Assembly of TES basement and Implementation of TCs in the basement | CNRS |
| **10-14/01/2022** | 2nd shipment of materials from Spain to France | ARRAELA - CNRS |
| **9-13/05/2022** | Construction and pre-assembly of the formworks of the wall in Spain | ARRAELA |
| **9/06/2022** | 3rd shipment of materials from Spain to France | ARRAELA - CNRS |
| **10/06/2022** | Starting of the erection of TES tank at THEMIS site (France) | ARRAELA |
| **13-17/06/2022** | Implementation of insulation slab and bottom formwork. Starting of construction of reinforcements for concrete wall | ARRAELA |
| **20/06-09/07/2022** | Assembly of inner and outer formworks for the wall | ARRAELA |
| **11/07/2022** | Construction of bottom slab in concrete | ARRAELA |
| **14-15/07/2022** | Installation of the inner formwork. Reinforcements of the formworks are set | ARRAELA |
| **19/07/2022** | Installation of the outer thermal insulation | ARRAELA |
| **25/07/2022** | Construction of the wall in concrete | ARRAELA |
| **26-29/07/2022** | Internal reinforcements are removed. Pipes and bottom diffusor are implemented. Bottom supporting grid is installed. Top cover is pre-adjusted. | ARRAELA |
| **01-15/08/2022** | Preparation of the filler bricks (cuts) | CNRS |
| **16/08/2022** | Installation of a crane at THEMIS site | CNRS |
| **17-31/08/2022** | Installation of filler bricks and implementation of the instrumentation (TCs) | CNRS |

## 2.2 Pictures of the construction

*Figure 1: Civil works [25-29/10/2022]*

*Figure 2: Construction of bottom formwork (left) and intermediate grids (right) [01-05/11/2021]*

*Figure 3: 1st shipment of materials from Spain to France [08-12/11/2021]*

*Figure 4: Construction of top cover of tank in Spain [15-19/11/2021]*

*Figure 5: Construction of reinforcements and preparation of other materials in Spain [29/11-03/12/2021]*

*Figure 6: Assembly of TES basement and Implementation of TCs in the basement [13-17/12/2021]*


*Figure 7: 2nd shipment of materials from Spain to France [10-14/01/2022]*

*Figure 8: Construction and pre-assembly of the formworks of the wall in Spain [09-13/05/2022]*

*Figure 9: 3rd shipment of materials from Spain to France [09/06/2022]*

***Figure 10: Implementation of insulation slab (left) and bottom formwork (center). Starting of construction of reinforcements for concrete wall (right) [13-17/06/2022]***

***Figure 11: Assembly of inner and outer formworks for the wall [20/06-09/07/2022]***

***Figure 12: Construction of bottom slab in concrete [11/07/2022]***

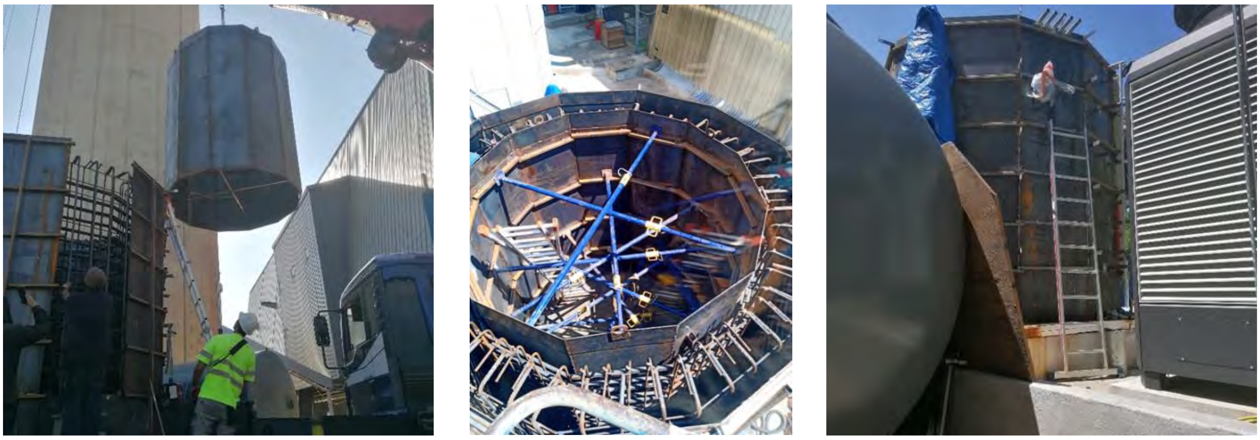

***Figure 13: Installation of the inner formwork (left). Reinforcements of the formworks are set (center & right) [14-15/07/2022)***

***Figure 14: Installation of the outer thermal insulation [19/07/2022]***

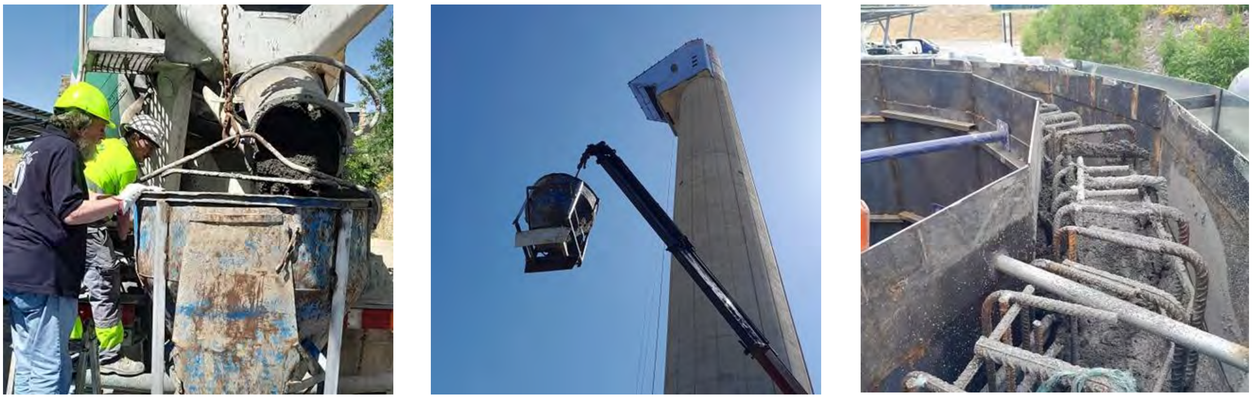

***Figure 15: Construction of the wall in concrete [25/07/2022]***

***Figure 16: Internal reinforcements are removed (left). Pipes and bottom diffusor are implemented (center). Bottom supporting grid is installed. Top cover is pre-adjusted (right) [26-29/07/2022]***

***Figure 17: Installation of a crane at THEMIS site [16/08/2022]***

***Figure 18: Installation of filler bricks and implementation of the instrumentation (TCs) [17-31/08/2022]***

# 3. SITUATION ON 31 AUGUST 2022

The Grant Agreement of POLYPHEM ends on 31 August 2022. At this date, the thermal energy storage system is not yet completed. The tank is erected, insulated and the connections with the oil pipes are finished. Although a strong effort has been dedicated to the implementation of the filler bricks and the instrumentation embedded in the filler bed, the rate of achievement of this part of the work up is 75%. The remaining implementation work will be done in the beginning of September 2022.