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ABraytCSPfuture

Air-**Brayt**on Cycle **C**oncentrated **S**olar **P**ower **future** plants via redox oxides-based structured thermochemical heat exchangers / thermal boosters

Deliverable D1.4.

Second version of revised project management plan.

Dissemination Level: Public

WP1 Project coordination and management

Date: 30.06.2025

https://www.abraytcspfuture.eu/

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Disclaimer

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1.1	30.06.2025	Updated with final partner feedback	Christos Agrafiotis	DLR
1.2	30.06.2025	Final Review	George Karagiannakis	CERTH

About the Project

ABraytCSPfuture sets forth an innovative, carbon-neutral way for implementing the highly efficient air-Brayton gas turbine power generation cycles into future air-operated Concentrated Solar Power (CSP) plants. Air-Brayton cycles are used in traditional power plants where, however, involve fossil fuels combustion via pressurized air. *ABraytCSPfuture*'s carbon-neutral approach aims at achieving higher solar-to-electricity efficiencies, vital for competitiveness of CSP and non-reachable by either PVs or molten salts and thermal oils, increasing in parallel significantly the plants' storage capability. The project will develop and demonstrate a first-of-its-kind compact, dual-bed thermochemical reactor/heat exchanger unit that will transfer heat from a non-pressurised air stream to a pressurised one, while also operating as a thermal booster, raising the temperature of the pressurized stream to the level required for Brayton cycles. Furthermore, the volumetric solar energy storage density of air-operated CSP plants will be significantly increased by rendering their current sensible-only regenerative storage systems to hybrid sensible-thermochemical storage ones within the same storage volume. Both these functionalities will be materialized by thermochemical reactor/heat exchanger units comprised of non-moving, flow-through porous ceramic structures (honeycombs or foams) based on earth-abundant, cost-efficient, non-toxic oxide materials and exploiting reversible reduction/oxidation reactions of such oxides in direct contact with air, accompanied by significant endothermic/exothermic heat effects. The proposed technology is set forth by an interdisciplinary partnership spanning the entire CSP value chain, comprised of leading research centres, universities, innovative SMEs and large enterprises, including ancillary services providers and technology end-users.

Deutsches Zentrum fuer Luft- und Raumfahrt e.V., **DLR**	DE	
Centre for Research & Technology Hellas, **CERTH**	EL	
University of Twente, **UT**	NL	
Fundación CENER, **CENER**	ES	
Fundación TEKNIKER, **TEKN**	ES	
Fraunhofer Gesellschaft zur Foerderung der angewandten Forschung e.V., **FHG (IWKS)**	DE	
DESTINUS Energy BV, **DEST**	NL	
KRAFTBLOCK GmbH, **KB**	DE	
LANDSON Emission Technologies A/S, **LET**	DK	
COBRA Instalaciones y Servicios S.A., **COBRA**	ES	

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This deliverable is part of a project that has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement no 101084569

Executive Summary

The present document constitutes Deliverable D1.4 "Second version of revised project management plan" developed within WP1 of the HORIZON EUROPE 2020 ABraytCSPfuture project, according to the project current progress. The document lists the modifications that had to be implemented in administrative aspects due to the developments in the project during the 2nd reporting period, i.e. from Month 16 to Month 32 of the project, and is an update to Deliverables *D1.1 Project Management Plan with Gantt chart and Work Breakdown Structure*, submitted in M4, and *D1.3 First version of revised project management plan*, submitted in M20. With respect to the technical aspects, most of the Workpackages (WPs) proceeded according to schedule, the first two milestones not only were achieved successfully within the initially foreseen timeframe but exceeded substantially the performance targets set. Several currently available results are considered by the consortium as breakthroughs beyond the current state-of-the-art of redox oxides-based thermochemical storage materials. However, delays in some other WPs with respect to Deliverables due and Milestones scheduled occurred. These delays are assessed as manageable by the consortium with only minor prolongation of some subsequent tasks and therefore not requiring major revisions with respect to the management of the technical part of the project.

Changes with respect to the DoA

Deviations from the DoA at this point of time concern basically WP4 and specifically Tasks 4.3 and 4.4. The respective Deliverable 4.3 has been delayed for 8 months and this will result in a concomitant delay of the therein dependent D4.4 and achievement on Milestone M3.

As of the time of preparation of the present deliverable (M32), it is assessed that these delays will not affect the overall state of the project, but only some tasks of WP5 that have to be extended for 3 months with respect to their originally foreseen end date, whereas, overall, WP5 does not have to be prolonged. This assessment is based on the fact that the two chronologically first milestones corresponding to WP2 and WP3 were met successfully within the initially foreseen timeframe, exceeding the performance targets set. The experimental results and know-how gathered so far will compensate for the delays and ensure the achievement of the following Milestones with only minor delay.

1. Introduction

Deliverable 1.4 describes the current status of the project at the end of Month 32 and assesses this status vs. the initial project planning based on the Description of Action (DoA) in the proposal and its modifications during the Grant Agreement preparation procedure. It is produced within the Management and Coordination work package (WP1) in order to outline a clear picture of the project status at the end of its second reporting period (RP2) and the work performed from Month 17 to Month 32, i.e. from March 1st 2024 to June 30th, 2025. A detailed description of the technical results during this period will be presented in the respective 2nd Progress report due within 60 days from the end of RP2, i.e. on August 31st, 2025 (Month 34). The current document's purpose is to concisely evaluate the work plan and the overall management approach adopted so far in order to ensure that tasks are completed on time, resources are allocated appropriately, and high performance/quality of results of the project is guaranteed vs. the initial targets set at the beginning of the project. Furthermore, any delays in project work, Deliverables and Milestones are mentioned and assessed and the corrective actions already set forth or further needed are described. In this respect, the document also contains a brief outline of the technical progress achieved so far and its assessment vs. the foreseen Milestones, in order to serve as a roadmap for the second periodic report, the respective progress review meeting and the course of the project during the next period until its end.

2. Project management

2.1 Official reporting

According to Article 21.2 of the Grant Agreement, the project is divided into three reporting periods (RPs) as follows:

- RP1: from Month 1 to Month 16 (i.e. November 1, 2022 – February 29, 2024).
- RP2: from Month 17 to Month 32 (i.e. March 1, 2024 – June 30, 2025).
- RP3: from Month 33 to Month 48 (i.e. July 1, 2025 – October 31, 2026).

Within 60 days from the end of each RP, a Report must be submitted to the granting authority by the PC, i.e. two Periodic Reports and one Final Report are due in total. The Reports are mandatory and linked to interim and final payments by the granting authority. Their requirements and contents are described in the Grant Agreement and also elaborated in D1.1.

The 1st Periodic Report was submitted on time. The overall assessment was that "*The project has achieved most of its objectives and milestones for the period, with relatively minor deviations.*" Following a Progress Review Meeting (see Section 2.3 below), the interim payment was implemented and the corresponding parts of funding were forwarded accordingly to the beneficiaries. The submission of the present Deliverable coincides with the end of RP2 and initiation of the preparation of all aspects necessary for the completion and submission of the 2nd Periodic Report.

2.2 Internal reporting

Even though initially considered as an option, no internal reporting was judged necessary during the course of the project so far. Frequent (typically monthly) WP and Task meetings were organized, while Project Progress meetings were organized every 6-months. This allowed for close and efficient monitoring of the technical progress, while all partners remained dedicated to the execution of their activities. Thus, it was judged as redundant to impose yearly reporting measures.

2.3 Project Review Meetings

As already described in D1.1, at the end of each reporting period and in association with the submission of the relevant progress reports, the Project Coordinator will organize three respective Project Review Meetings among all partners, the EC officer and possibly external experts invited by the EC. Taking into account the 60-days maximum period allowed for the submission of the periodic reports and a reasonable time for the EU officer and any external reviewer(s) to assess them, such Project Review Meetings are tentatively foreseen for M19, M35 and M48 from the date of the Project's commencement.

2.4 Project Deliverables

The list of the project deliverables foreseen until the end of the project, their level of dissemination (e.g. public, confidential), and their due dates are listed in Annex 1 of the Grant agreement (GA-A1). Overall, 34 Deliverables are foreseen. The list of Deliverables in chronological order, their type and due dates compared to their actual submission dates are listed in Table 1 and depicted schematically along the timescale of the project in Figure 1 on the same timescale, together with the due dates of all official reports.

Figure 1: ABraytCSPfuture's Deliverables per WP (submitted and due), reports and progress review meetings timeline.

Table 1: ABraytCSPfuture Deliverables and current status (due dates in green submitted on time, deviations from submission due date in red, orange-shaded due in 2025, grey-shaded due in 2026).

Del	Title	Leader	Nature	Due/actual date (M)
D1.1	Project management plan with Gantt chart and Work Breakdown Structure	DLR	R-PU	3 / 4
D1.2	Quality Management Plan	DLR	R-PU	48/ 3
D8.1	Launch of project's website, protected acronym, electronic communications network and social media account	DLR	DEC-PU	6
D8.2	Data Management Plan	DLR	DMP-PU	6
D2.1	Computationally screened shortlisted redox compositions for further research	DLR	R-PU	9
D1.3	First version of revised project management plan	DLR	R-PU	16
D2.2	Powder-redox relevant properties variation with temperature & pressure	DLR	R-PU	18
D2.3	Thermochemical properties variation with temperature	CERTH	R-PU	18
D2.4	Optimized redox oxide powder formulations for model ceramic pieces manufacture	CERTH	R-SEN	18
D4.1	First version of chemical/transport processes simulation results in redox structure	UT	R-PU	24
D4.2	First version of simulation results of redox structures thermochemical expansion	DLR	R-PU	24
D7.1	Report on environmental-friendly materials selection	FHG	R-PU	24
D8.3	Dissemination and exploitation plan	DLR	R-PU	24
D4.3	Structured objects geometries and design of dual-bed unit for integrated TCS /thermal booster operation	TEKN	R-PU	24 / 32
D3.1	Properties of structured ceramic model specimens as a function of temperature.	CERTH	R-PU	27/28 (20 days)
D3.2	Optimal porous structures for combined TCS/thermal booster operation based on combined activity, thermo-mechanical stability and cyclability performance	CERTH	R-SEN	27/28 (4 days)

D3.3	Optimized redox oxide formulations and structured objects for proof-of-concept-scale unit.	DLR	R-SEN	27/28 (20 days)
D4.4	Complete flowsheet and Piping & Instrumentation diagram.	DLR	R-PU	27 / 35
D5.1	Optimized redox powders scaled-up powder synthesis/processing protocols.	CERTH	R-PU	30/ 31 (29 days)
D1.4	Second version of revised project management plan	DLR	R-PU	32
D5.2	Proof-of-concept high-oxide-content porous structured objects shaping/sintering protocols	LET	R-PU	36
D7.2	Key stakeholders' meetings identifying environmental/ social/economic impacts	FHG	R-PU	36
D8.4	Preliminary market study for proposed technology	CENER	R-PU	36
D5.3	Dual-bed storage prototype unit assembled, manufactured and installed on test rig facility.	KB	DEM-PU	39
D4.5	Process control scheme of STPP-scaled-up dual-bed unit.	TEKN	R-PU	45
D4.6	Complete flowsheet/analysis of optimized STPP-level integrated process	CENER	R-PU	48
D6.1	Report with results of extended in-service "thermal booster" operation campaigns	DLR	R-PU	48
D6.2	Report on in-service degradation of functional materials after longer-term cyclic operation and its impact on overall performance of technology components and systems.	CERTH	R-PU	48
D6.3	Report with final evaluation of technology vs. key performance indicators set.	DLR	R-PU	48
D7.3	LCA study, socio-economic and environmental impact.	FHG	R-PU	48
D7.4	Technology scale-up prospects, business cases and required policy framework	COBRA	R-PU	48
D8.5	Workshop on project's final achievements	DLR	DEC-PU	48
D8.6	Dissemination/exploitation activities and post-project plan.	DLR	R-PU	48
D8.7	Virtual Reality tool for dissemination of project results.	DLR	DEC-PU	48

As can be seen from Table 1, most of the Deliverables were submitted on time or with minor delays not exceeding one month. The single exception is *D4.3 Structured objects geometries and design of dual-bed unit for integrated TCS /thermal booster operation* originally scheduled for M24 and the depended-on-the-outcome-of-that *D4.4 Complete flowsheet and Piping & Instrumentation diagram.* The Consortium has notified the Project Officer in 06.2025 for an anticipated delayed submission of D4.3 to M29; however, the actual delay was longer than that initially anticipated and D4.3 was eventually submitted on M32. This had as a direct consequence that also *D4.4 Complete flowsheet and Piping & Instrumentation diagram* that depends on the results and input from D4.3 could also not be submitted on time. Detailed explanations on the reason of these deviations, consequences, mitigation measures and revisions of the workplan are discussed in Section 4 of this document after the analysis on the achievement of Milestones elaborated in Section 3 below.

3. Project Milestones

The Milestones set to assess the progress of the project as described in the Grant Agreement are also summarized here in Table 2. Crucial Milestones have been set for before all Assessment Meetings to be used as a measure for such decisions. Milestones 1, 2 and 3 in particular are relevant to the end of the 2nd Reporting period.

Table 2: ABraytCSPfuture Milestones (due dates in green achieved on time, deviations from submission due date in red, orange-shaded due in 2025, grey-shaded due in 2026).

MS No	Milestone name	WP No	Lead part.	Due date	Means of verification	Status
1	At least one composition with minimal or no expensive/critical/ health harmful materials, capable of long-term cyclic TCS operation and thermal boosting.	2	2. CERTH	M18	Results of lab-scale test campaigns with mixed oxides qualifying at least one composition in powder form achieving: sensible + TCS energy density ≥ 300 kWh/m^3 for at least 500 cycles in the temperature range 300-1100 ^{o}C.	**Achieved M18**
2	Structured objects made of optimized material compositions with maximum active material content selected for manufacture of the	3	2. CERTH	M24	Manufacturing protocols and results of lab-scale test campaigns with structured objects, identifying at least one structure geometry with structural integrity & tolerable dimensional changes for at least 200	**Achieved M24**

	proof-of-concept unit.				cycles, and: TCS + sensible energy density ≥ 300 kWh/m^3.	
3	Proof-of-concept unit dimensions finalised; test site layout defined.	4	5. TEKN	M27	Corresponding 3D integration layout including devices, piping, sensors, dimensions, location etc.	**Delayed**
4	Completion of proof-of-concept-unit-scale porous structured redox - material ceramics manufacture and qualification.	5	9. LET	M36	Powder shaping/sintering protocols leading to structured objects based on the developed materials. All required structures for proof-of-concept unit manufactured, passed quality tests and delivered	**Not yet due**
5	Completion of components manufacture, unit assembly and installation on test platform.	5	10. KB	M39	Full proof-of-concept prototype system delivered and installed on test platform; all required peripherals coupled, ready for start of operation.	**Not yet due**
6	Validation of extended operation, post-service components examination and technology proof-of concept.	6 5	1. DLR	M48	Results of WP5 for at least 100 cycles indicating that developed materials meet operation, thermomechanical stability/lifetime targets of energy density ≥ 300 kWh/m^3 and pressurized air temperature > 950 °C.	**Not yet due**
7	Targeted concept and relevance for commercial-scale integration demonstrated through qualified scenarios.	4 7	4. CENER	M48	Completion of validated full-scale system model for at least 1 plant integration scenario and feasibility analysis indicates operation/cost targets are met: materials production cost ≤ 2€/kg; LCOE < 7 c€/kWh_e	**Not yet due**

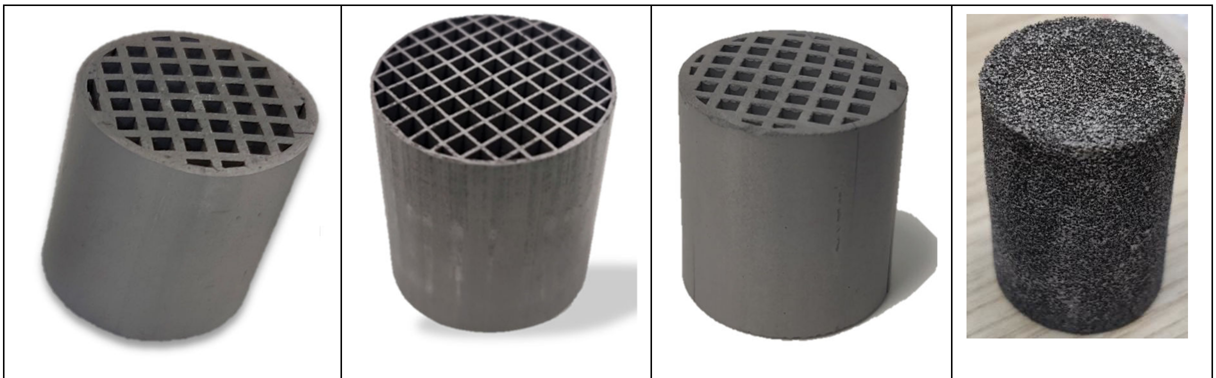
The following comments are relevant to the project Milestones foreseen to be achieved until this period:

M1: *At least one composition with minimal or no expensive/critical/health harmful materials, capable of long-term cyclic TCS operation and thermal boosting* **not only was achieved on time, but the technical targets defined for its verification were by far surpassed**. 510 cycles in the temperature range 300-1100 °C with the $CaMnO_3$ (CMO) composition **in powder form** were performed by CERTH and the results showed no deactivation of redox performance, as identified by the value of non-stoichiometry parameter δ. Comparative XRD and SEM/EDS analysis revealed no compositional or phase alteration between the pristine and aged powders. The calculated volumetric energy density values determined under properly designed operating protocols, lied in the range of **467 – 476 kWh/m³ for the pristine $CaMnO_3$ powder** and in the range of **464 – 468 kWh/m³ for the aged one**, i.e. **more than 1.5 times that of the targeted value of *≥ 300 kWh/m³***. It has to be also mentioned that other powder compositions like $Ca_{0.9}Sr_{0.10}Mn_{0.90}Fe_{0.10}O_3$ (CS10MF10O) and $Ca_{0.9}Sr_{0.10}Mn_{0.75}Fe_{0.25}O_3$ (CS10MF25O) - tested at lower number of cycles - not only exhibited redox performance (i.e. δ) similar to CMO composition but in addition higher specific heat capacity and absence of the detrimental orthorhombic-to-cubic phase transition (see D2.2, D2.3, D2.4).

M2: *Structured objects made of optimized material compositions with maximum active material content selected for manufacture of the proof-of-concept unit* **was also not only achieved on time, but also the technical KPIs and targets defined for its verification were by far exceeded**. As elaborated in D3.2. two different specimens (listed in Table 3) spanning two different perovskite redox compositions ($CaMnO_3$/CMO and $Ca_{0.90}Sr_{0.10}MnO_3$/CS10MO) and two different porous structure geometries (one foam and one honeycomb, shown in Figure 2) were identified as *able to demonstrate structural integrity & tolerable dimensional changes for at least 200 cycles* while yielding combined *TCS + sensible energy density ≥ 300 kWh/m³* whereas two more specimens have demonstrated the similar capability for 72 and 80 cycles. The honeycomb structures in particular **exceeded the targeted combined TCS + sensible energy density by almost three times.** These heat effects resulted to a substantial thermal boosting effect, which is one of the main targets of the project. The tests by CERTH have demonstrated the capability of these perovskite-made structures to reversibly store and release heat during cyclic heating/cooling and materialize it **as a clearly manifested temperature rise of an air stream flowing through them during discharging. As a matter of fact, to the best of the consortium's knowledge this is the first time that the ability of a perovskite to generate repeatable heat effects upon cyclic redox operation is demonstrated experimentally. The temperature of air passing through the structures in the course of the exothermal oxidation can be increased by up to 140°C while the respective temperature increase on the surface of the structures was found to be up to 206°C.** The redox operation of the perovskite structures is repeatable and stable and the addition of 10% at Sr (CS10MO case) is highly beneficial on the energetic and redox performance of the structured bodies. A clear positive effect on the structural stability is also evident cf. the undoped CMO structures. The use of relatively dense structures (i.e. high bulk/geometrical density) is beneficial in terms of energetic performance and thus future scaled-up structures to be manufactured in the frame of project's activities should consider this general guideline.

Table 3: Calculated Q_{total} (volumetric energy storage density) values for the 4 redox lab-scale structures studied so far.

Structure	Total number of cycles carried out	Q_{total} (kWh/m^3)	% Sensible / % Thermochemical
CMO 59 cpsi honeycomb	72	**800**	73 / 27
CMO 111 cpsi honeycomb	80	**405**	84 / 16
CS10MO 59 cpsi honeycomb	203	**840**	68 / 32
CS10MO 60 ppi foam	214	**350**	64 / 36



59 cpsi CMO	111 cpsi CMO	59 cpsi CS10MO	60 ppi CS10MO

Figure 2: Photographs of the 4 in-house manufactured redox all-perovskite lab-scale structures (three honeycombs and one foam) studied so far.

M3: *Proof-of-concept unit dimensions finalised; test site layout defined*, has not been achieved on time. This milestone concerns the availability of all information necessary to build up the proof-of-concept test unit, which eventually became available only at M32 of the project as elaborated in the end of Section 2 above.

4. Deviations from the DoA, explanations and mitigation measures

Deviations from the DoA at this point of time concern basically WP4 and specifically Tasks 4.3 and 4.4. As already mentioned, *Task 4.3. Layout and design of prototype hybrid sensible-TCS/heat exchanger pressurized unit for "thermal-boosting" operation,* initially foreseen to end on Project M24 culminating to D4.3, was actually extended to M32. Consequently, *Task 4.4. Flowsheet, piping and instrumentation,* initially foreseen to span M22-27 culminating to D4.4 and the accomplishment of Milestone M3, has to be extended until the end of M35 (September 2025). It has to be mentioned that preparatory work in this task not directly dependent on D4.3 (e.g. market searches for high-temperature valves, potentially required auxiliary gas heaters etc.) has already started.

The reason why D4.3 could not be submitted as originally scheduled is that on the one hand a lot of experimentally measured parameters for the materials and structures of interest had to be collected (Cp, conductivity, mechanical strength, geometries, reaction kinetics etc.) within work in WP2 and WP3 and supplied to partner TEKNIKER, responsible for the work and preparation of the Deliverable, as inputs for the design of the dual bed unit. Ongoing simulation work has shown a high sensitivity of the design characteristics on specific thermal, physical and thermochemical properties of the materials and the shapes selected for the manufacture of the unit. Given the high temperature span foreseen to be employed for hybrid sensible-TCES testing (300-1100°C) it was crucial **to measure in-house such properties as a function of operating temperature** and not just simply rely on values from the literature extrapolated to the higher operation temperature limit. Such campaigns were performed on several shortlisted perovskite compositions as well as on sensible-only compositions and structures. However, such required sophisticated equipment on the one hand was not always immediately and directly available to the partners and on the other hand was prone to operational malfunctioning needing hence a lot of "debugging" activities.

Furthermore, the reduction/oxidation kinetics of the system under study, which are crucial for the correct design and dimensioning of the dual bed unit, had to be accurately determined and validated on structures similar to that eventually to be used in the unit, i.e. honeycombs and/or foams. As elaborated in several deliverables, the peculiarity of the perovskite system under study is that the reduction and oxidation reactions take place in a quasi-continuous manner with operating temperature once an onset temperature for the reduction reaction is exceeded. Therefore, tailor-made thermochemical testing protocols simulating the real unit operation conditions had to be devised by the project partners in order to develop a theoretical approach with physical and chemical meaning, since such information has not been expressed in the relevant literature as such for this kind of applications. Furthermore, the relevant experimental campaigns performed under such protocols involve a lot of trial-and-error experimentation as well as time-consuming multi-cycle heating and cooling tests with a variety of powder and shaped specimens in different test rigs (TGA and electrically-heated furnaces, respectively). Last but not least, the results so obtained have to be incorporated in a kinetics model able to be able to be verified and validated against multiple process conditions in the aforementioned wide temperature range.

An equally important reason for the delay is that, in combination with the ongoing simulation work on WP4, a lot of personnel resources were allocated in **investigating experimentally feasible scalable routes for the shaping of the large-scale structured porous ceramic building blocks of this dual-bed unit. Indeed, any simulation results concerning optimisation of porous structures** with respect to properties like porosity, number of channels per unit of cross-section area, pressure drop, mechanical strength etc., and consequent dimensions and designs, **are pointless if such ceramic structures cannot be effectively produced by standard industrial practices.**

Therefore, a lot of effort so far was dedicated to demonstrate the achievement of the first two, very crucial technical milestones of the project namely MS1 and MS2. The successful achievement of these two Milestones and in fact the spectacular exceeding of their targeted objectives has made the consortium to re-consider options for the structured bodies, approaches for their manufacture and inception of more preliminary tests and properties' measurements. In this respect, the consortium partners dedicated a lot of effort on the exploration of various, potentially efficient routes for the production of a variety of possible redox structured building blocks. As elaborated in D5.1, significant effort was dedicated in developing protocols for scaled-up relatively optimum redox structures at a scale/quantity to cover the needs of the envisaged proof-of-concept pressurized dual-bed unit in the framework of the necessary experimental work of WP5, providing a roadmap to a **practical scaled-up manufacturing of redox structures** for the needs of the project and beyond. Specifically, an alternative strategy, not initially foreseen at the time of the proposal was conceived, comprised of **mixing the raw powders** of the targeted composition, shape the **scaled-up structures from this mixture** and calcine the structured raw mixture, thereby achieving **synthesis of the perovskite and the necessary sintering of the body in a single step.** Such a procedure could bypass two energetically intensive steps: the raw materials sintering stage in order to synthesize the required perovskite composition and the subsequent powder milling step required to render the heavily sintered powder suitable for further processing and shaping into the targeted porous structures. Representative extruded shapes of such structures are shown in Figure 3 before (reddish ones) and after sintering (grey) so that the extend of shrinkage can be visually appreciated. Figure 3e shows typical schematics and examples of how units of larger diameter can be assembled from extruded pieces of smaller diameters and proper shape. It should be borne in mind that there is a limitation in diameters (with respect to extruders and dies) up to which single-block cylindrical pieces can be extruded. Units of higher diameter can be assembled for instance from a "central" cylindrical piece and peripheral circular segment-shaped extruded pieces as shown therein, or, alternatively, from specimens of square cross-section placed next to each other and some of them trimmed and placed in the periphery (not shown); hence the choice of extruding such specimens as well.

It has to be stressed that, to the best of the consortium knowledge, the points mentioned above, i.e. experimental measurements of thermophysical properties of such perovskites within this temperature range, extraction of validated phenomenological kinetic models for reduction and oxidation and production of all-perovskite made robust porous structures in such a variety of shapes and dimensions **have not been reported so far in the open literature.** The consortium **considers these results as breakthroughs beyond the current state-of-the-art of redox oxides-based thermochemical storage materials.** Even if this route of shaping the mixture of the raw powders is proven difficult to be followed eventually, significant experience on large-scale perovskite powder synthesis and extrusion of the pre-fired perovskite powder has been acquired so far in the project's course. In this respect the partners feel confident that at this stage, where the materials, shapes and dimensions of the dual bed unit have been determined at a first level, they can successfully address the profound challenges of identifying the most favourable scaling-up protocol to achieve in-principle feasible manufacturing of scaled-up extruded honeycombs and provide the required ceramic pieces with the required properties on time within WP5 for the realisation of the next project steps.

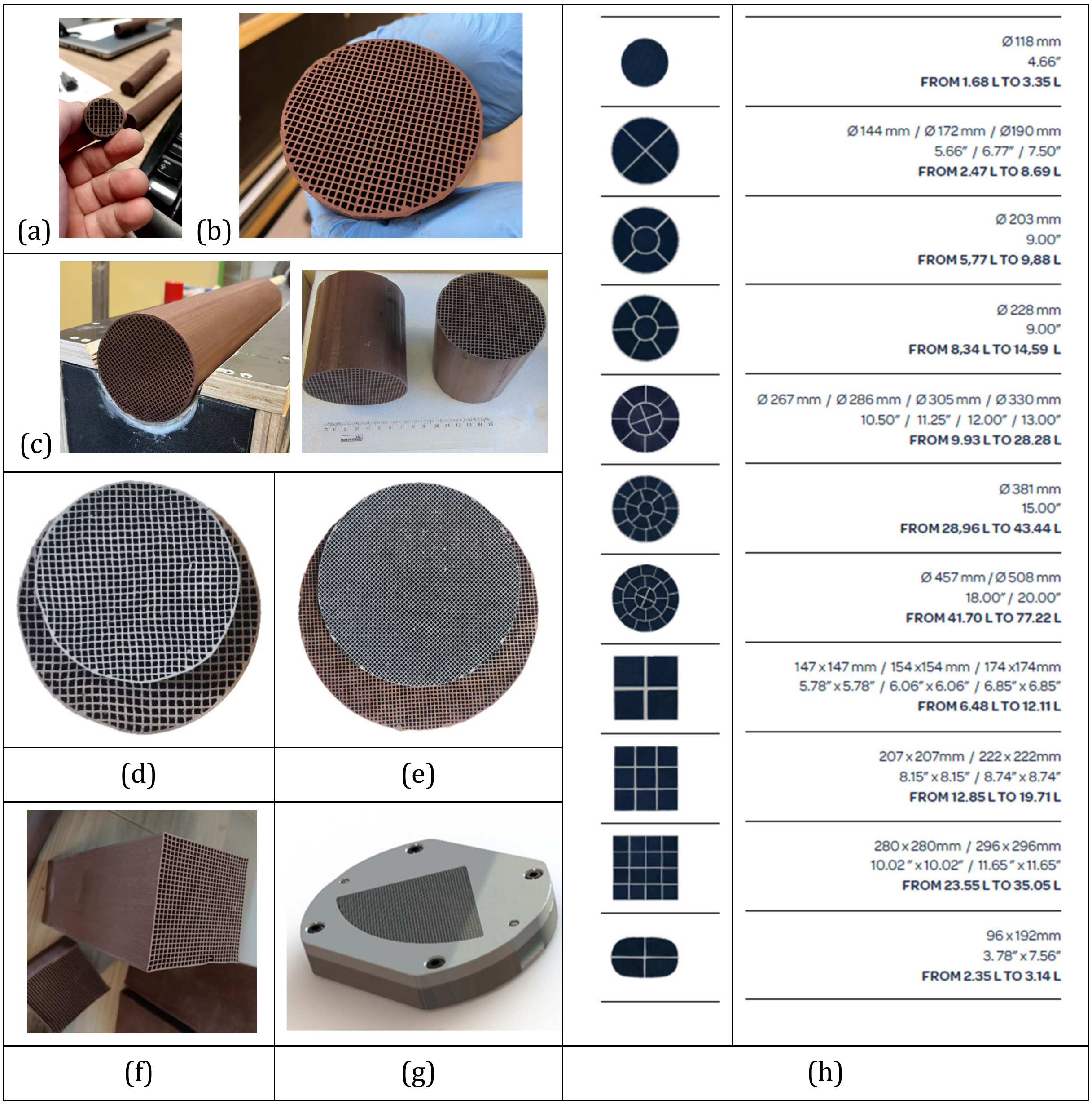


Figure 3: Representative extruded perovskite honeycombs by LET before (reddish) and after sintering (grey): (a), (b) cylindrical specimens with square channels produced using a 90 cpsi extrusion die, of Ø 25 and 90 mm, respectively; (c) macroscopically defect-free 90 mm samples; (d), (e) comparison of shrinkage during sintering of 90 mm and 118 mm extruded samples, respectively; (f) specimens of square cross-section with square channels; (d) circular segment extrusion die and (e) scaling up the cross-section via assembling of segments of various sizes with extrusion dies available at LET.

This delay in Tasks 4.3 and 4.4 WP4 will not affect the rest of the WP4 tasks as these are scheduled to last until later on (T4.1, T4.2 until M42) or the end of the project (T4.5 until M48). Furthermore, the delay **will not affect the overall state of the project, but only some tasks of WP5** that have to be extended for 3 months with respect to their originally foreseen end date, whereas, overall, WP5 does not have to be prolonged. The consortium believes that all the experimental results having been currently gathered will compensate for the delays of D4.3 and D4.4 and ensure the achievement of the following Milestones with only minor delay. These changes are further elaborated in Section 6, in conjunction with the updated Gannt Chart of the project.

With respect to the other WPs, as far as WP2 and WP3 are concerned, there were no deviations or critical issues from their respective work plans. Not only the work proceeded as planned, but all their objectives and associated milestones (MS1 and MS2) were successfully fulfilled in time and surpassed the targets set. However, the duration of Task 3.4 has been practically extended until M30 in order to have time and solid results to conclude more safely on the heat storage potential of a variety of structures and compositions as well as on their microstructural and thermomechanical performance. This has facilitated the multi-cyclic study of as many as possible different structures and compositions in order to obtain the maximum possible volume of information regarding the behaviour of such structures to ultimately define the optimum structure(s)-composition(s) combination and to interact with WP4 in terms of modelling input/outputs (i.e. kinetics, further advise on operational modes etc) as already explained. Meanwhile, a suitable (not necessarily optimum) composition, CS10MO has been defined for the needs of WP5, and the first batches of sintered powder of the order of 35 kg have been already synthesized by LET (Figure 4).

Figure 4: Large-scale synthesis of CS10MO powder (WP5). Left: premixed quantity of of ca. 35 kg of raw materials; right: perovskite sintered powder.

There is no major deviation from the work plan in the framework of WP7. Within WP8, even though the foreseen target of presentations at international conferences (20) has already been surpassed, there is a hysteresis with respect to that of open access publications in scientific journals (currently 2 vs. a target of 20). On this issue, the results obtained so far, both quantitatively as well as qualitatively, suffice for the preparation of at least three publications and the partners involved are currently working on drafting the relevant manuscripts.

5. Project meetings

5.1 In-presence Meetings

The project bi-annual in-presence meetings of the whole consortium with participation and representation of each project partner took place as scheduled:

- Kick-off Meeting, 11.2022 (M1), DLR, Cologne, Germany.
- 6-Month Meeting, 06.2023 (M8), University of Twente, Enschede, Netherlands.
- 12-Month Meeting, 12.2023 (M14), Fraunhoffer IWKS, Alzenau, Germany.
- 19-Month Review Meeting, 05.2024 (M19), DLR, Brussels, Belgium.
- 24-Month Meeting, 11.2024 (M25), On-line.
- 30-Month Meeting, 06.2024 (M32), TEKNIKER, Eibar, Spain.

The next in-presence meeting will be the 2nd Progress review meeting, tentatively scheduled after submission of the 2nd Periodic Report for RP2 (from M17 to M32), due on August 31st, 2025.

5.2 Remote Meetings

Regular remote meetings within each ongoing WP were implemented as scheduled, i.e. every 3 months or even more often as per specific needs, for the effective cooperation and communication among the WP partners and the materialisation of the requirements within each WP. The actions discussed and agreed are documented in meeting minutes. Trans-WP remote meetings, e.g. between the LCA, powder synthesis and powder shaping-relevant WPs also took place, to exchange necessary information and clarify any issues.

6. Project planning

The overall project planning consists of the work breakdown structure (WBS) and the Gantt chart presented in sections 7.1, 7.2 respectively. This planning is and will be continuously updated in the course of the project and used by the coordinator to control the progress of the work tasks as well as the timely preparation of deliverables and achievement of milestones. Updates with respect to the initial plan are elaborated below.

6.1 Work break down structure (WBS)

ABraytCSPfuture is scheduled as a 48-month project, comprised of 6 Research/ Innovation Workpackages (WP2-WP7), covering the technical activities necessary to develop the project's novel ideas, complemented by two WPs addressing its coordination and management (WP1) and actions for exploitation of the project's outcome, dissemination and communication of its results (WP8), respectively. The interrelation among WPs is visualized in the respective Pert diagram and their implementation in three phases as elaborated in D1.1 and D1.3 remains unchanged and as shown in Figure 5

The WBS shown in Figure 6 is based on the Pert diagram. Among the Research/Innovation Workpackages (WP2-WP7), four concern mainly experimental work. This work starts from WP2 with the synthesis of a large palette of redox powder compositions and their relevant characterisation and evaluation and proceeds to WP3 addressing the shaping and manufacture of lab-scale porous structures out of several shortlisted powder compositions and their testing in lab-scale test rigs; it then escalates to the construction and assembly of a modular, dual-bed Proof-of-Concept (POC) thermochemical reactor/heat exchanger/thermal boosting unit (WP5) and culminates with integration of the PoC unit in a test platform for the demonstration of the ideas set forth in the project (WP6). Throughout the project, this work is guided and supported by extensive design and simulation work, spanning the entire range from atomistic scale to the entire solar plant operation simulation level (WP4). In parallel the socioeconomic and environmental impacts of the proposed technology and its potential commercialization roadmap are addressed in WP7. The contents of each WP have been analysed in more detail in the GA and the relevant Deliverables submitted so far. As also elaborated in D1.1., the project's rationale is to build and operate a proof-of-concept demonstrator of the thermal boosting concept set forth out of material(s) with in principle satisfactory properties, even though these materials turn out eventually not to be necessarily the best possible ones. In this perspective, studies in WP2 and WP3 will continue after their respective milestones up to M42 investigating further the possibilities to develop "even better" compositions and structures through further optimization.

6.2 Updated Gantt chart

Based on the discussion in Section 4 above, the changes that have to be incorporated in the current version of the Project's Gantt Chart vs. the version included in *D1.3 First version of revised project management plan,* are summarised as follows and as such have been introduced in the accordingly modified, current updated version of the project's Gantt Chart, shown in Figure 7.

- *Task 3.4 Comparative microstructural and thermomechanical evaluation of porous structures and of hybrid sensible TCS operation* initially scheduled to last between M13-M18 has been practically extended until M30.
- *Task 4.3. Layout and design of prototype hybrid sensible-TCS/heat exchanger pressurized unit for "thermal-boosting" operation*, initially scheduled to last between M13-M24 has been extended to M32 (when relevant deliverable D4.3 was submitted).
- *Task 4.4. Flowsheet, piping and instrumentation,* initially scheduled to last between M22-M27 has to be extended to M35 (when relevant deliverable D4.4 will be submitted).
- Consequently, in parallel *Task 5.1 Kg-scale synthesis of optimized compositions of redox oxide material powders.* initially scheduled to last between M25-M30 has to be extended to M33.
- *Task 5.2. Manufacture of proof-of-concept-reactor-scale versions of porous redox structured objects,* initially scheduled to last between M28-M36 has to be extended by

two months, to M38. The corresponding Milestone *M4. Completion of proof-of-concept-unit-scale porous structured redox -material ceramics manufacture and qualification* will hence also be delayed by 2 months and accomplished in M38.

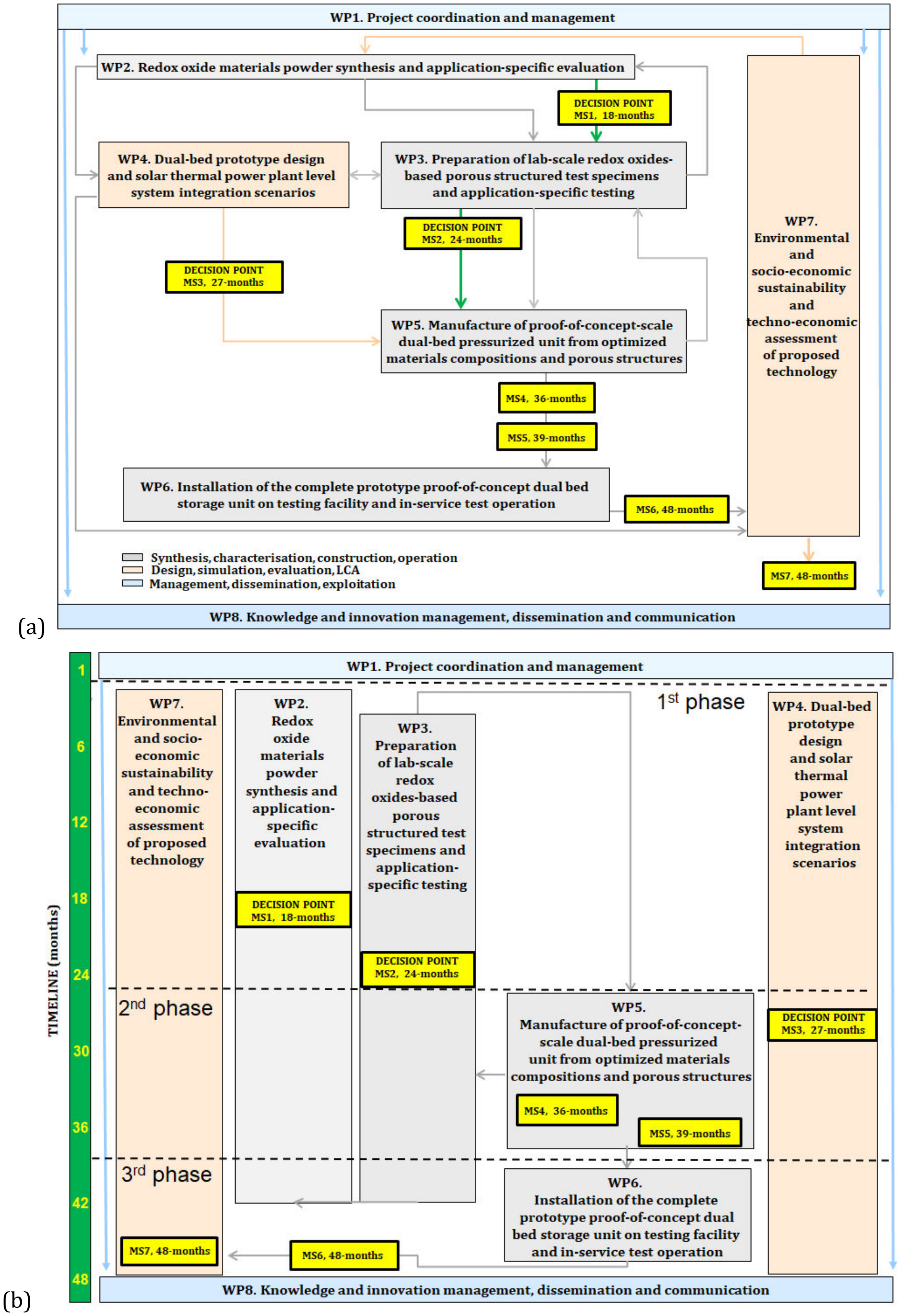


Figure 5: (a) Pert diagram and (b) conceived phases of ABraytCSPfuture project.

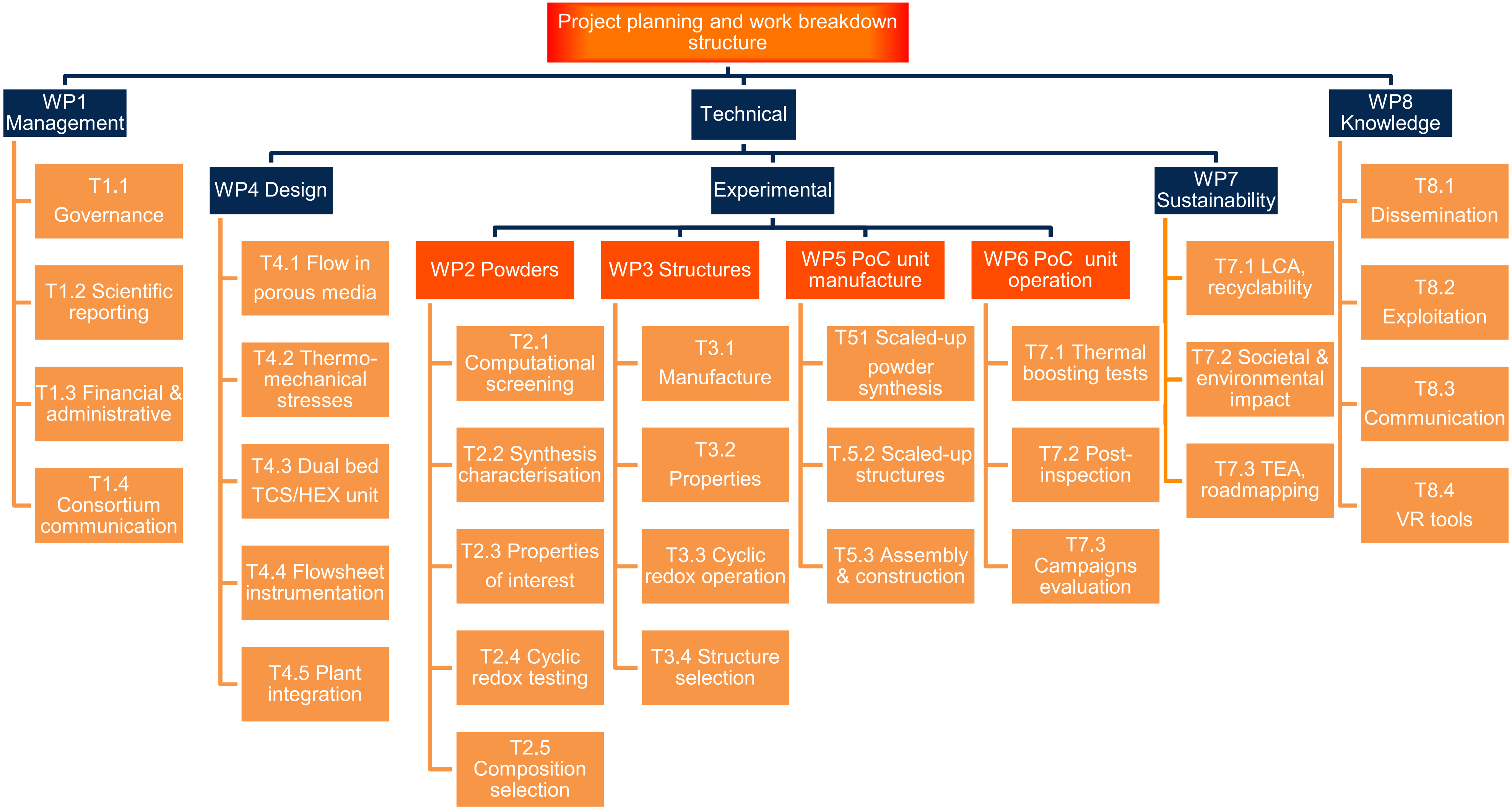


Figure 6: ABraytCSPfuture work breakdown structure (Acronyms: TCS/HEX: ThermoChemical Storage / Heat Exchanger, PoC: Proof-of-Concept, LCA: Life-Cycle Assessment, TEA: Techno-Economic Analysis, VR: Virtual Reality).

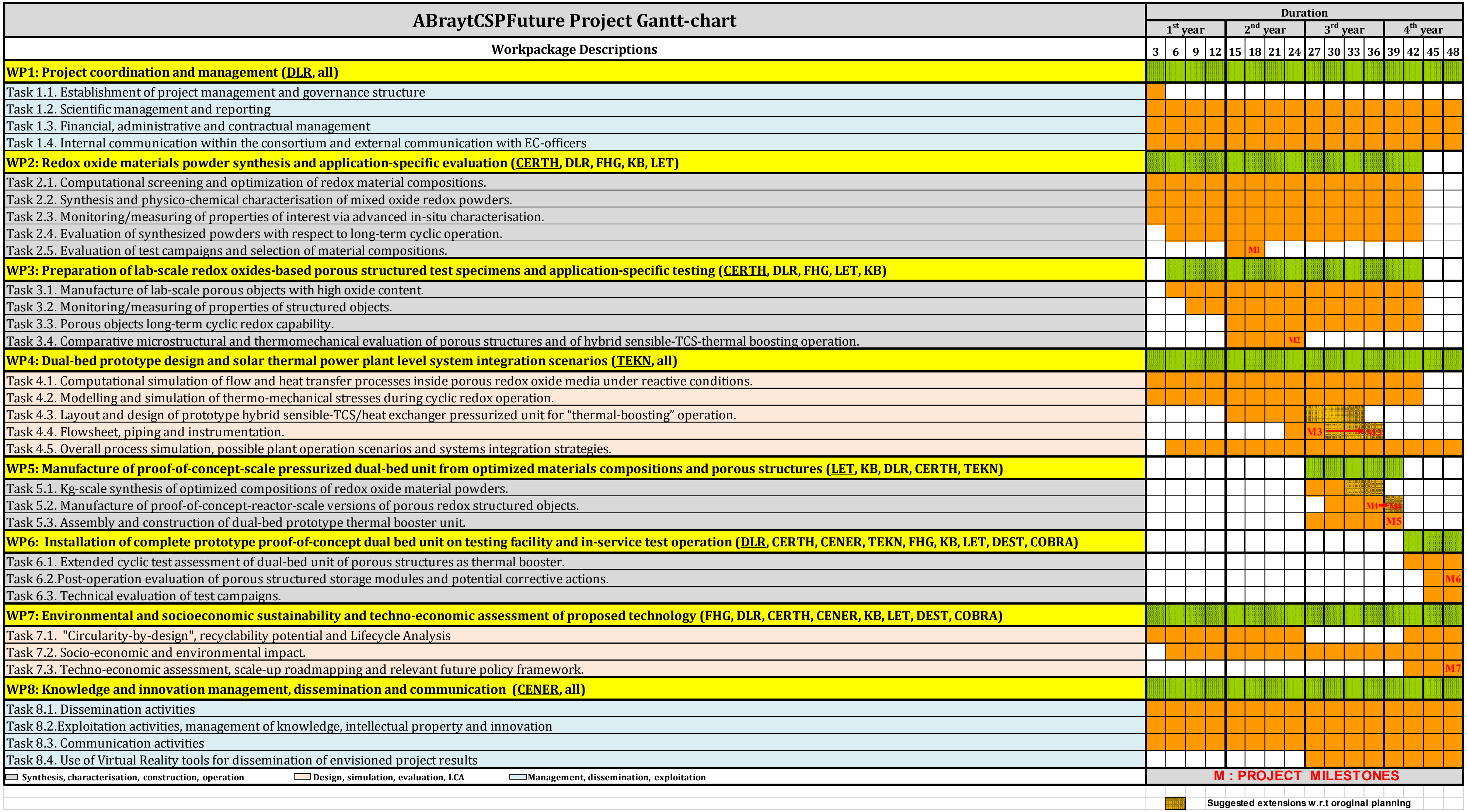


Figure 7: ABraytCSPfuture updated Gantt chart (30.06.2025).

7. Conclusions

On the technical part, the work performed so far has mostly proceeded according to schedule. The two chronologically first milestones corresponding to WP2 and WP3 were met successfully within the initially foreseen timeframe and exceeded substantially the performance targets set.

Deviations from the DoA at this point of time concern basically WP4 and specifically Tasks 4.3 and 4.4. The respective Deliverable 4.3 has been delayed for 8 months and this will result in a concomitant delay of the therein dependent D4.4 and achievement on Milestone M3.

These delays will not affect the overall state of the project, but only some tasks of WP5 that have to be extended for 3 months with respect to their originally foreseen end date, whereas, overall, WP5 does not have to be prolonged. The consortium believes that all the experimental results having been currently gathered will compensate for the delays and ensure the achievement of the following Milestones relevant to WP5 with only minor delay. Therefore, no further essential revisions in addition to the above are currently needed with respect to the management of the technical part of the project.