PROJECT FINAL REPORT

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4.1 Final publishable summary report

Executive summary

Within the TCS Power project, thermochemical energy storages operating at high temperatures were investigated and developed for a direct integration into advanced CSP plants. Since one of the main advantages of CSP plants - dispatchable renewable electricity – depends strongly on cost-effective and efficient thermal energy storages, the project focussed on two different basic reactions for energy storage that proposed low cost storage capacities: On the one side manganese oxide reacting reversibly with oxygen at temperatures above 700 °C was addressed. Besides the good availability of the raw materials, efficient integration strategies into high temperature solar towers propose synergies since the heat transfer fluid (air) can be directly used as carrier for the reaction gas (oxygen). On the other side, the research focused on the reversible reaction of quick lime (calcium oxide) with water vapour. This material is already widely applied in several processes and therefore - already at present - available in large industrial scale. Due to its working temperature range between around 400 and 600 °C and potential synergies the reaction system was investigated as thermochemical energy storage for steam cycle based power blocks.

One of the main objectives of the project was an integrated approach for the development of the thermochemical energy storage. Starting with work package one, all three aspects of thermochemical energy storage were taken into account. These are the intrinsic material properties and their potential improvements as well as the requirements from the CSP plant that pose clear limitations and boundaries on integrational and operational aspects of thermochemical energy storages. The third aspect is related to the thermochemical reactor – the actual heat exchanger where the reaction takes place needs to fit to the requirement of the CSP plant as well as to the respective material properties.

Due to the specifications of the power plant on one side and the material properties on the other side, both thermochemical storage approaches focussed on the development of a reactor design that allows for a movement of the material through a reaction zone. Based on this concept, the reactor is designed to reach the required power level whereas the capacity can be easily increased by adding additional cheap tanks to store the required amount of reaction material. According to this overall project goal the improvement of the material mainly addressed the possibility to move reactive solids through the reaction zone. In case of the manganese oxide this was achieved by granulation of the reaction powder whereas in case of the calcium oxide, the enhancement of the flowability was addressed by the addition of nano-structured spacer particles to the reactive powder. The reactor development work packages consequently addressed a fluidized bed of reactive manganese oxide granules as well as a counter-current moving bed concept for the calcium oxide system. The first one was developed and brought into operation in lab-scale (100 Wh) whereas the latter one reached a pilot scale level of 10 kW power and 100 kWh capacity (~ 300 kg of material).

The process evaluation work package started with different integration concepts for the two storages taking the power block requirements as well as the available thermal power from the solar field at different sites into account. Based on a performance evaluation model and an up-scaling strategy for the two developed reactor concepts a techno-economic evaluation was done. It could be shown that the concept of separated capacity is clearly favourable for large storage quantities. However, future work should address the reduction of the overall complexity of the reactor. An important finding is that even if material modifications increase the cost for the storage material, it can be clearly beneficial if at the same time the reactor and system complexity can be reduced.

Main objectives of the project

Intermittence of renewable power supply and high power generating costs are the major technical and economical obstacles to widespread commercial use of regenerative energy sources (RES). In contrast to photovoltaic (PV) or wind power, concentrated solar power (CSP) has the potential to provide dispatchable power on a defined capacity level by integrating large-scale thermal energy storage. Efficient, reliable and economic thermal energy storage (TES) technologies will thus improve economics and raise the market potential of CSP technology. Recent strategies to further improve CSP technologies are aiming at plant concepts with higher concentration factors resulting in higher operation temperature with consequently higher overall conversion efficiencies. This implies the need for medium and high temperature thermal energy storage technologies that can easily be integrated into the CSP plant at low cost. Such TES systems are considered to be one of the key factors for providing low cost electricity from solar power.

Thermochemical storage of energy has the potential for very high storage densities in comparison to other storage technologies. With thermochemical reactions (250 to 400 kWh/m^3) about four times the storage density of latent heat storage (50 to 100 kWh/m^3) can be reached. However, the integration into respective processes as well as the efficient operation of thermochemical storages has been so far not properly understood. Therefore, one of the main objectives of the project was an integrated approach for the development of the thermochemical energy storage. Since a thermal energy storage demands more than only a reversible chemical reaction, the three main aspects of thermochemical energy storage were taken into account in parallel work packages (compare also Figure 1):

- Storage Material – reversible chemical reactions at the desired temperature
- Storage Concept – reactors that enable an efficient exchange of energy
- Process integration – operation strategies that fit to the requirements of the plant

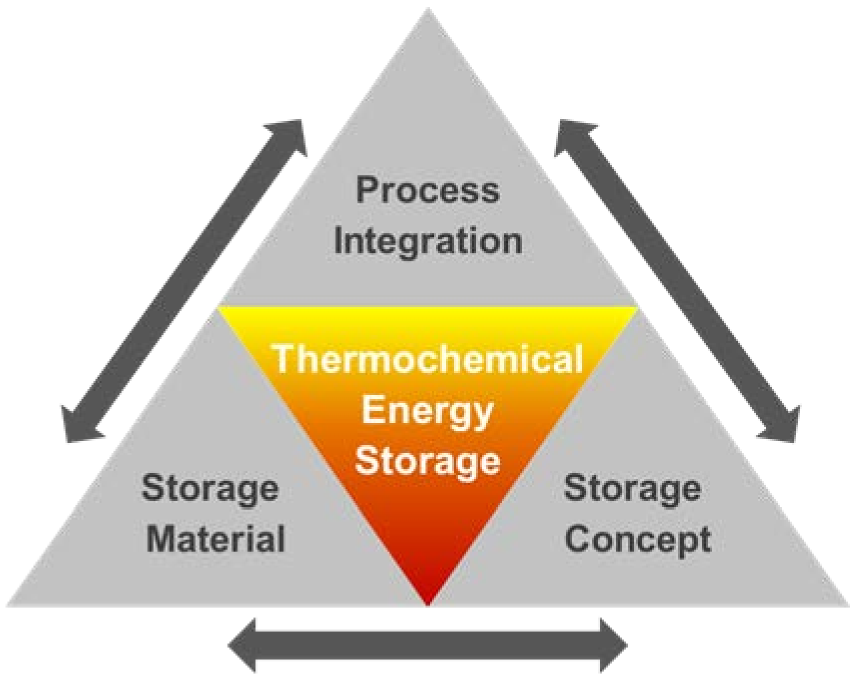


Figure 1: The three main aspects of thermochemical energy storage

By utilizing low-cost materials as TCS reaction systems large storage capacities can be realized without high investment costs for the material. Therefore, the project focussed on two different basic reactions for energy storage that proposed low cost storage capacities:

- Manganese oxide reacting reversibly with oxygen at temperatures above 700 °C
- The reversible reaction of calcium oxide with water vapour at temperatures around 500 °C

Additionally, if the concept of a moving bed is realized and the storage capacity is dispatched from the power level of charging and discharging, the capital cost for the reactor is independent from the desired storage capacity – it only has to fulfil the power level requirements. This feature could be an enormous advantage compared to other storage technologies and could bring down LCOE as well as CAPEX cost dramatically. Due to promising results on the material and lab-scale level, it was therefore decided during the mid-term review to focus on the proof of functionality of TCS systems with moving bed and thus separation of power from storage capacity. This was done for both reaction systems in parallel but with different reactor concepts:

- A fluidized bed concept for manganese oxide
- A counter-current moving bed concept for calcium hydroxide

The overall project's line of development is summarized in Figure 2.

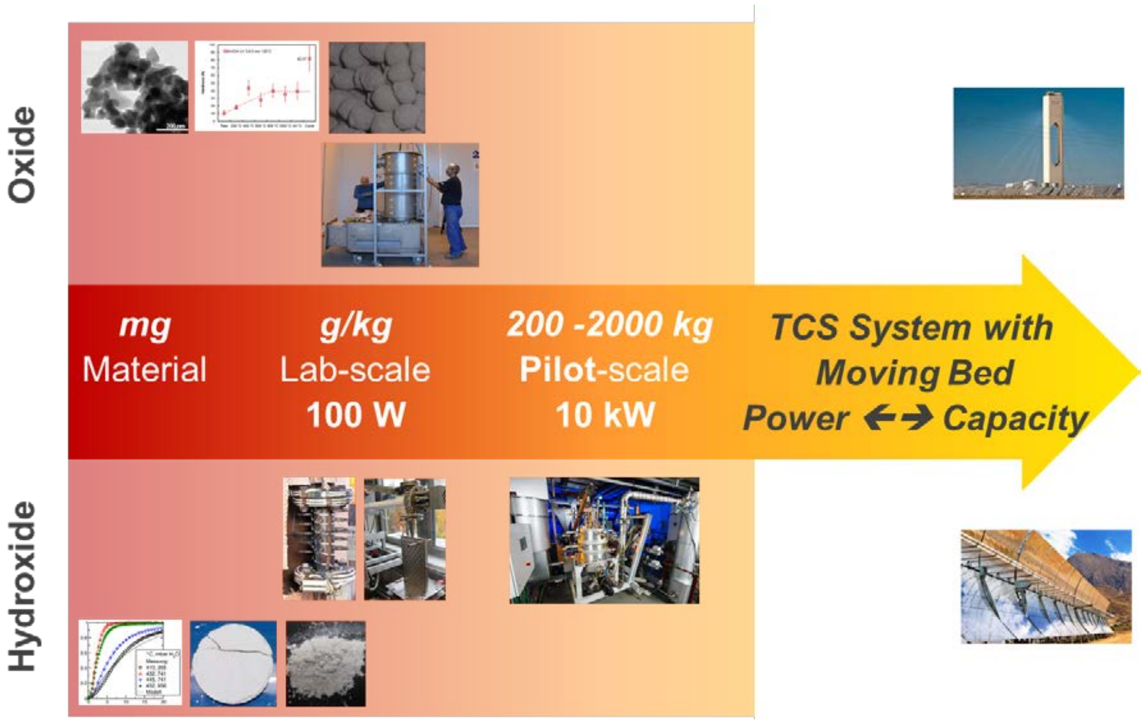


Figure 2: Line of development for both thermochemical storages addressed within TCSPower

The improvement of the material mainly addressed the possibility to move the reactive solids through the reaction zone. In case of the manganese oxides a granulation of the reaction powder was chosen as material modification since promising results have been achieved until the mid-term. Fe-doped MnOx were found to improve the cyclability of this material and accordingly that modified materials was used hereafter. In case of the calcium oxide, the enhancement of the flowability by the addition of nano-structured spacer particles to the reactive powder became the main aspect. The reactor development work packages consequently addressed a fluidized bed of reactive manganese oxide granules as well as a counter-current moving bed concept for the calcium oxide system. Due to different development statuses at the mid-term, the first one was developed and brought into operation in lab-scale (100 Wh) whereas the latter one should reach a pilot scale level of 10 kW power and 100 kWh capacity (~ 300 kg of material).

Except for these minor adjustments of the research focus of the project, the main objectives of the TCSPower project remained unchanged and were:

- Develop innovative solutions of thermal energy storage for the next generation CPS plant
- Research and development of two different TCS materials, namely redox reaction with manganese oxide and reaction of calcium oxide with water vapour
- Research and development of two different TCS reactor concepts – both with the detachment of power and capacity
- Experimental verification at relevant scale
- Development of first integration strategies into CSP plants
- Economic evaluation based on a first-of-its-kind pilot scale thermochemical storage.

Main S&T results

In order to achieve the scientific goals and technical targets of the TCSPower project mentioned above the work was organized in seven work packages. The basis for all further development was built in WP1 where the hydroxide and the redox reaction systems were evaluated as well as TCS system specifications were defined and translated into technical targets taking all aspects from material and TCS reactor side as well as CSP plant requirements into account. WP2 on TCS material development and WP3 on reactor development by simulation were conducted in parallel for the hydroxide and redox reaction system with strong cross linkage. Feasibility of the developed materials and reactor concepts was addressed in lab-scale in WP4. Based on the results achieved in the first two years of the project, the calcium hydroxide system was chosen to be tested in pilot-scale within WP5. However, due to successful optimization of materials, the WP4 was extended in order to test the fluidized bed concept with reactive manganese oxide granules in lab-scale. All aspects of development were underpinned in WP 6 by investigation of the TCS system on process level for system integration, up-scaling and final techno-economic evaluation of the TCS technology. The work package for coordination (WP7) completed the work program. The organisational structure of the TCSPower project can be seen in Figure 3.

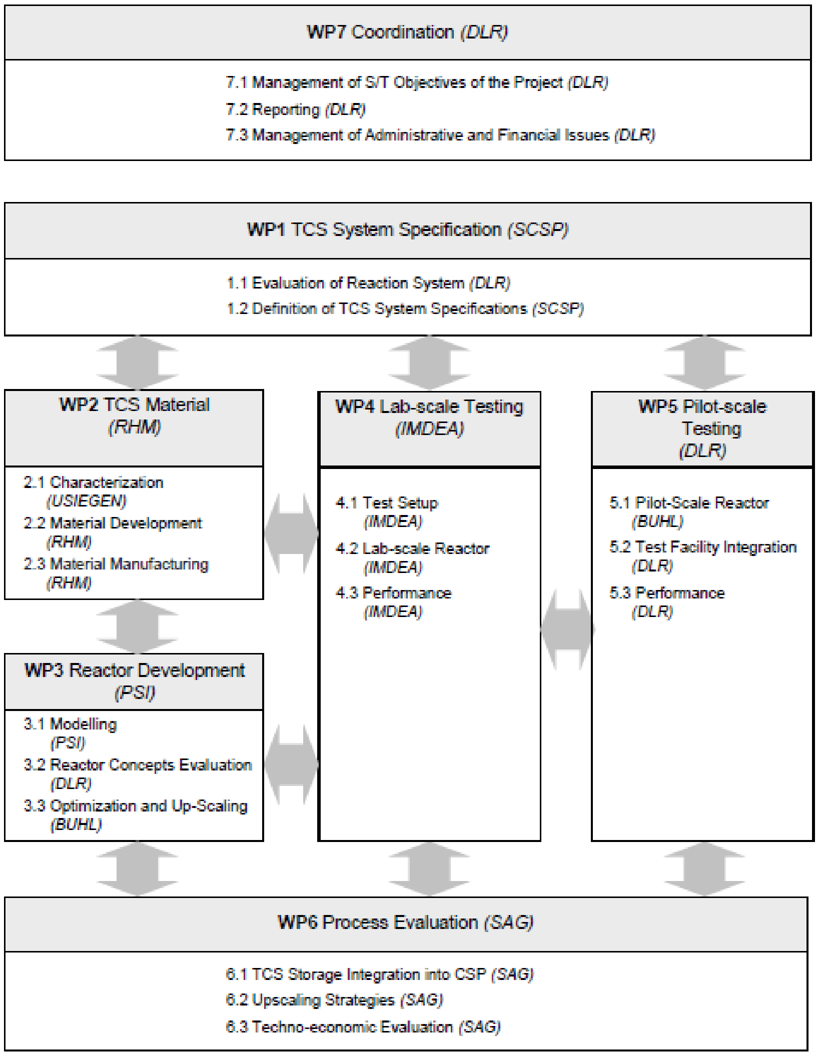


Figure 3: Organisational structure of the TCSPower project

In the following sections, the main results obtained by the project will be summarized. A brief description of activities performed in various work packages will be provided.

WP1 TCS System Specification

WP1 built the starting point of the TCSPower project. In WP1.1 DLR, RHM, IMDEA, PSI and USIEGEN evaluated the hydroxide and redox chemical reaction in thermodynamic equilibrium and in dynamic situations as a function of TCS system operating conditions (total pressure, reaction gas partial pressure and temperature).

Based on the results from WP1.1 and information from SCSP on requirements for thermochemical storage used with future trough technology and air-cooled central receiver technology all partners were involved in the establishment of high level specifications for the overall hydroxide and redox TCS systems and interfaces with the solar plant including distinct definition of technical and economic targets in WP1.2. The most important ones for the later development within the project were:

- Conditions for charging and discharging (mainly temperature levels)

- Large storage capacities of up to 12 h since dispatchability was seen as main advantage of CSP in comparison with other renewable energy technologies

- Hybridization of the plant (with a gas burner) in order to increase the annual operation days

- Plant size in the range of 125 – 150 MW_{el}

Some of the parameters for the different CSP plants are given in Table 1.

Table 1: Chosen parameters of the different solar plants

		Parabolic Trough			Tower
	Interface parameter	SuperCritical DSG	Subcritical DSG	Molten salt PT	Closed Volumetric Air Receiver
1	HTF design temperature at entrance to TCS	*450 - 470°C*	*530-540°C*	*550-580°C*	*1000°C*
1	HTF design pressure at inlet to TCS	270 bar	120 bar	17 bar	15 bar
2	HTF design temperature at exit from TCS	250°C	25°C [TBD]	290°C	420°C
	HTF pressure drop	<40 bar	TBD	<5 bar	< 1 bar

These specifications built the baseline for the development of the storage material and the reactor concepts in WPs 2, 3 and 4 and were constantly assessed and updated during the course of the project.
This information was completed with pre-existing experimental information of DLR and IMDEA at material and lab-scale level. Special attention was paid to existing knowledge on reversibility/cyclability and kinetics of the reactions – and to potential material modifications. Additionally, BUHL collected information on possible reactor concepts for the TCS system according to the material properties known in month three of the project.

WP2 TCS Material

The TCS material development in WP2 was devoted to extensive characterization and included elemental analysis, chemical analysis of overall composition and impurity levels, structural and morphological analysis of the crystallites, physical analysis of surface area, pore volume and density, determination of thermophysical properties and thermal analysis for investigation of thermodynamic equilibrium and reaction kinetics being used as input for simulation. As mentioned above, due to the project focus of detachment of power and capacity, the material improvements mainly addressed the possibility to move the material, maximizing as much as possible the stability. Therefore, in the following the two different approaches – the addition of nano-structured additives to enhance flowability and the preparation of reactive granules - are described separately.

CaO – increased flowability by addition of nano-structured particles

In order to identify the best options for optimization of the calcium hydroxide material with the best compromise between enhanced flowability, lowered agglomeration tendency of the powdery material, good reaction kinetics and thermodynamics in combination with a high rate of conversion and heat gain, respectively, the influence of different types of nanostructured additives (SiO_2, Al_2O_3, mixture of SiO_2 and Al_2O_3, SiC, BN, $CaCO_3$, carbon) was investigated during the project. Following graphic (Figure 4) shows the principal working plan:

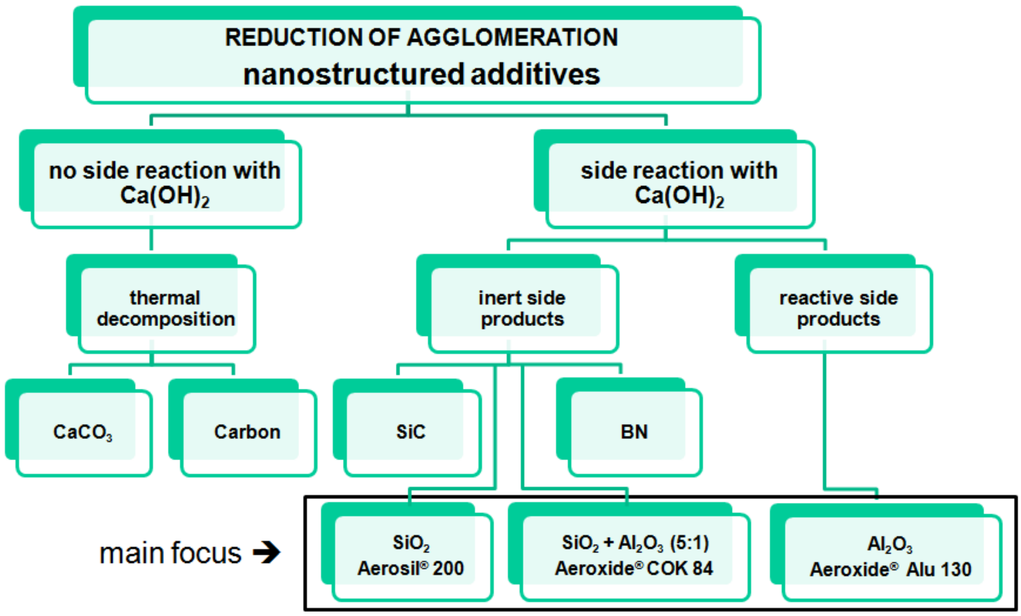


Figure 4: Principal working plan

Changes in the material during long-term thermal cycling were investigated with characterization methods, e.g. by thermo-physical analysis related to thermodynamic equilibrium, heat of reaction, reaction kinetics and rate of conversion employing methods of thermal analysis (TGA, DSC, DCA). Crystal phases have been identified employing XRD measurements, subsequent Rietveld-analysis of the concerning patterns gave the phase composition of the respective samples. Electron microscopy has been used for the examination of the morphological structure; the particle size distributions were determined by laser granulometry and for the determination of specific surface areas gas adsorption has been employed. All results were correlated to the physicochemical modification of the substrates and powder flow tests of samples before and after cycling.

In general the nanostructured additives have a positive influence in prohibiting the agglomeration tendency of the pure calcium hydroxide material and some of them significantly enhance the flowability of the powdery material, but formation of side products, respectively decomposition occurs during cycling. Also the flowability of the modified materials is affected during cycling.

Figure 5 shows the improved flowability of the modified materials in comparison to the pure $Ca(OH)_2$ reference material.

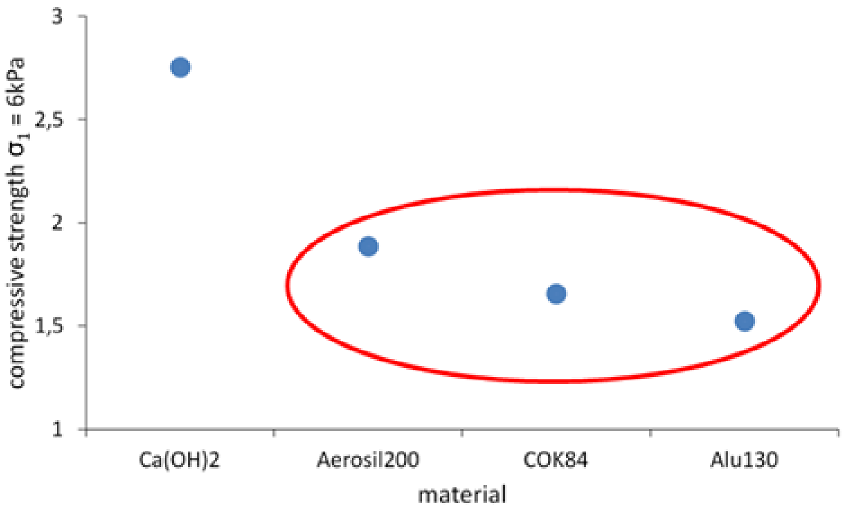


Figure 5: Improvement of flowability

Table 2 shows the side products which are formed during cycling for the different nanostructured additives detected via X-ray diffraction after the cycling process.

Table 2: Phase composition of samples after cycling

sample	w% $Ca(OH)_2$ (XRD)	w% $CaCO_3$ (XRD)	w% CaO (XRD)	w% side product (XRD)	w% amorphous (XRD)
$Ca(OH)_2$ raw	96.8	1.8	-	-	1.4
$Ca(OH)_2$ + 12w% SiO_2	57.2	2.8	0.3	13.6 + 19.0 reinhardbraunsite + dicalciumsilicate	6.0
$Ca(OH)_2$ + 12w% Al_2O_3	67.4	-	0.3	17.3 + 3.4 + 2.2 katoite + C_3A + mayenite	8,8
$Ca(OH)_2$ + 12w% SiO_2 + Al_2O_3	58.1	2.3	0.2	12.2 + 17.0 reinhardbraunsite + dicalciumsilicate	4.8
$Ca(OH)_2$ + 10w% TiO_2	43.1	32.3	2.8	13.7 perovskite	8.1
$Ca(OH)_2$ + 10w% SiC	39.3	8.3	-	47.0 spurrite	5.4
$Ca(OH)_2$ + 2.5w% BN	84.8	0.8	-	13.6 takedaite	0.7

Examples for the influence of the nanostructured additives are shown in Figure 6 where the rate of conversion and the elapsed time for hydration and dehydration for modified samples with SiO_2 and Al_2O_3 in comparison to the pure $Ca(OH)_2$ reference material is depicted.

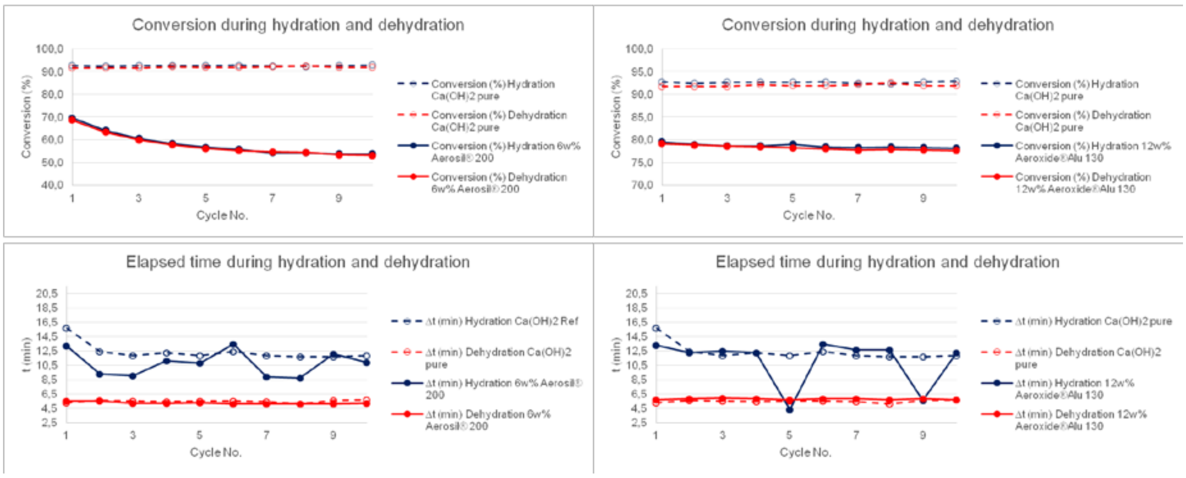


Figure 6: Percentage rate of conversion and elapsed time for hydration and dehydration reaction during cycling with simultaneous thermal analysis.

The material modified with 12w.-% of Aeroxide Alu 130® showed the best compromise between enhanced flowability, lowered agglomeration tendency of material, good reaction kinetics and thermodynamics in combination with a high rate of conversion and heat gain, respectively, and was therefore successfully produced in sufficient amount for the prototype unit and delivered to project partner for implementation into pilot-scale reactor.

MnOx – granules for fluidized bed concept

In order to be able to operate a fluidized bed reactor with reactive particles, a minimum size of the particles has to be achieved. Based on an extensive investigation, granulated [2.0-3.6mm] iron-doped MnOx was selected as TCS material for the final lab reactor tests at IMDEA (WP4). In TGA tests, the performance of granulated iron-doped MnOx (5%Fe) is comparable to the corresponding powder material. Over 200 cycles were obtained with the powder material while tests on the granules were stopped after ~120 cycles.
Additionally, a pilot production (30kg) of a MnOx doped with 5mol% Fe was successfully carried out. The material showed good thermal behaviour as shown in Figure 7. Granulation parameters were studied to optimize the production yield as well as the initial hardness of the granules. It has been shown, that the method of preparation of the granules is important to improve re-oxidation kinetics (Figure 8).
Nevertheless as initial hardness of the dried granules is still judged too small, a curing-hardening step has been studied. A heat treatment step at 750°C for 4 hours is adequate as shown on Figure 9.

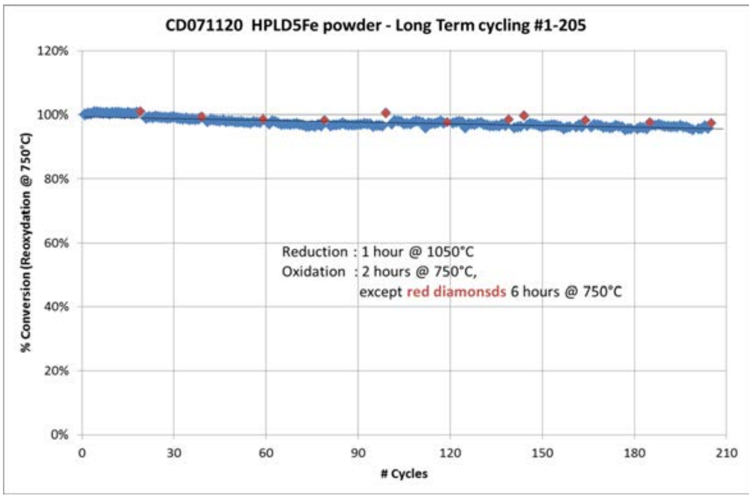


Figure 7: Pilot Material – TGA thermal cycling in Air (from compressor) flow 75ml/min on ~1g of powder

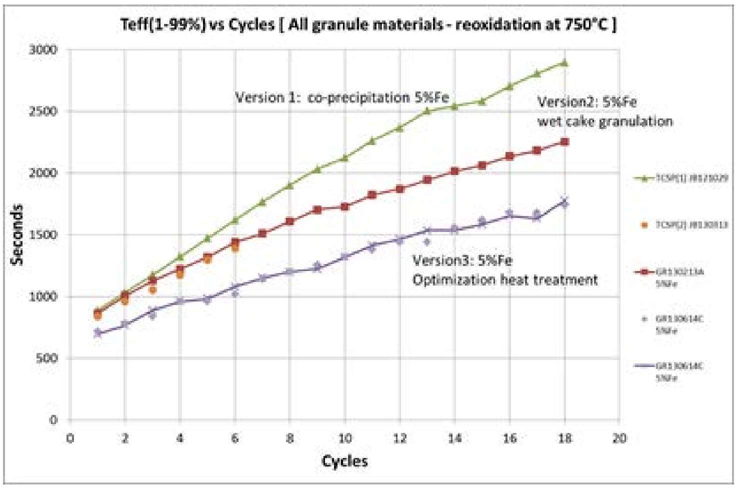


Figure 8: Influence of preparation method on kinetics (as measured by Teff parameter, 'Teff' is defined as the time in seconds to re-oxidize the TCS material from 1% to 99%)

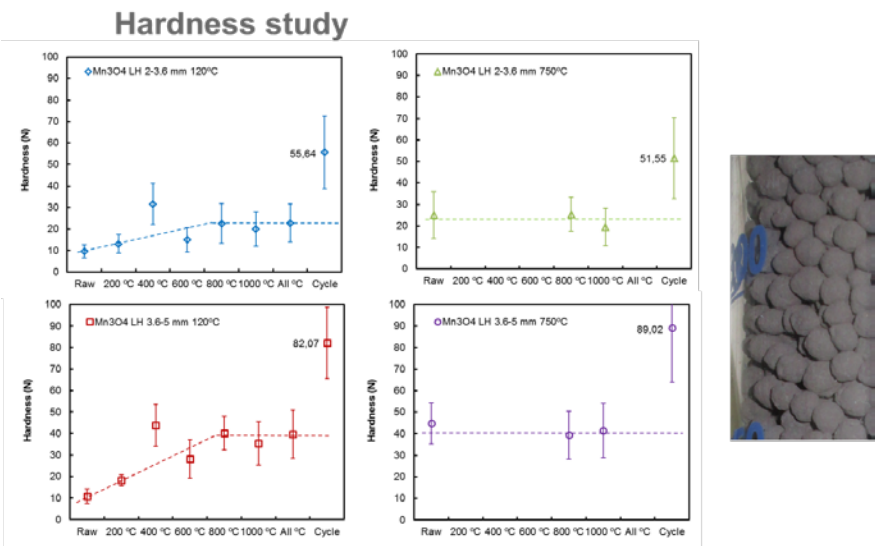


Figure 9: Hardness study (IMDEA) on standard Mn3O4LH granules

In order to minimize the cost of the active material (raw materials and process steps), several modifications were tested. The direct granulation of standard Mn_3O_4LH and iron oxides (Fe_2O_3 with different particles size distributions, FeOOH, etc.) was checked without any improvement compared to the co-precipitation method. Good results were obtained in terms of granule hardness and kinetics by the granulation of the wet cake coming from the press filter. This avoids a costly drying/handling/storing step in the overall process. Heat treatment of the granules (curing-hardening) can also be advantageously performed in a rotary kiln.

<u>Material characterization in more realistic gas atmospheres:</u>
Granules of iron-doped MnOx were subjected to thermal cycling in more a challenging atmosphere. Air containing up to 15% CO_2 or air containing water vapour (3%, 7% and ~20%) as well as some NH_3 (~5%) were used during thermal cycles of granules. No adverse effect on the O_2 exchange efficiency was observed (Figure 10 and Figure 11).

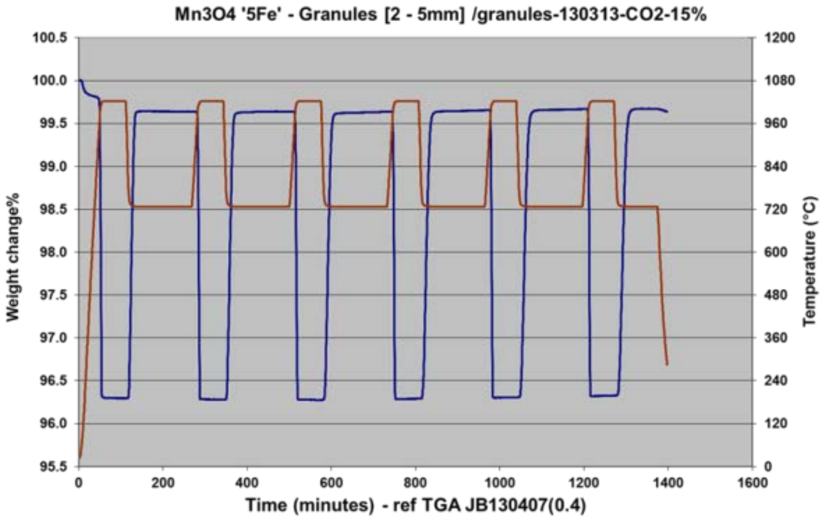


Figure 10: Cycle behavior of 5mol% Fe MnOx granules cycles in a mixture of air and CO_2 (85/15).

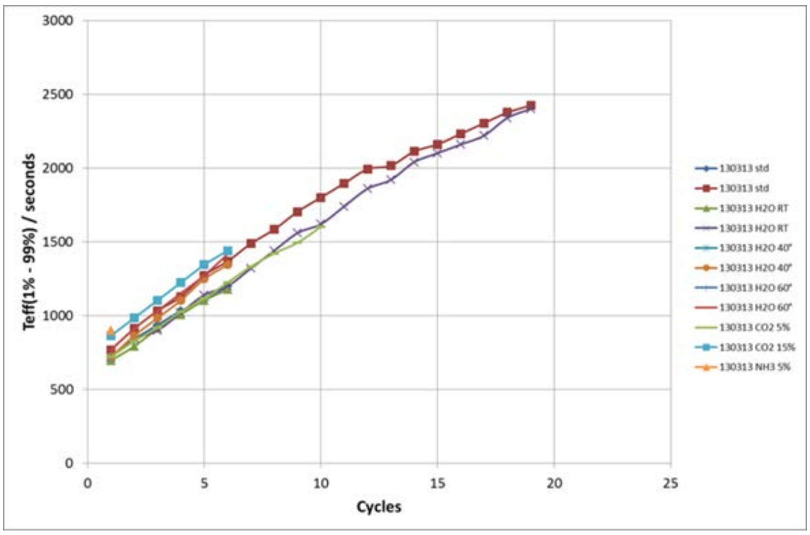


Figure 11: Kinetics of 5mol% Fe MnOx granules cycled with different atmospheres. No difference with cycling in air.

WP3 Reactor Development

The reactor development in WP3 had its starting point with a detailed modelling in WP3.1. Additionally, different reactor concepts were evaluated in WP3.2 on single unit storage level (particle, pellet, fixed, spouted or moving bed) by parametric studies of the reactor dimensions, operating conditions, as well as chemical and thermo-physical characteristics of the material. However, one – at the beginning underestimated - aspect of work package 3 was the detailed analysis of integration possibilities of different reaction concepts into the power plant. As mentioned above, this aspect is crucial for thermochemical storages – especially due to the high reaction temperature. The last part was dedicated to the development of the reactor of the pilot plant unit.

Reactor design and modeling – case of MnOx

The lab-scale reactor for manganese oxide has been designed to work at pressures between 1 to 10 bar and to withstand temperatures above 1100 ºC. Figure 12 illustrates the final lab-scale reactor design. It consists of three stacked bodies, each one composed by an external stainless-steel enclosure and two insulating linings. Internal and external linings are made of ceramic bricks and insulated ceramic blankets. Various cordierite rings were inserted in the bottom of each body in order to secure the mechanical stability of each body. The external reactor radius and the thickness of the insulation layers were obtained from computational fluid calculations using the commercial software COMSOL Multiphysics® assuming a safe external enclosure temperature (see Figure 13). The internal wall is composed by a 650mm cylindrical ceramic tube and a conical ceramic piece. This allows for a fast diminution of the velocity at the reaction chamber exit, decreasing the particle entrainment. The gas distributor is located at the bottom of the cylindrical pipe. The internal distribution of components inside the reactor has been designed taking into account the thermal expansions of different components during the reactor heating and cooling.

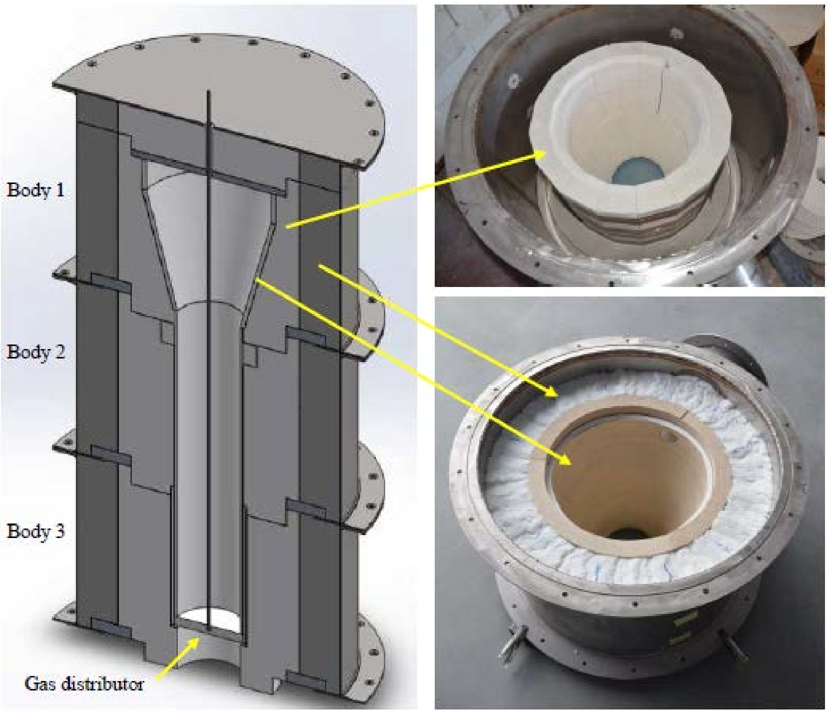


Figure 12: (Left) Reactor final design including an axial cross section; (Right) Views of the upper reactor body during its manufacturing. Arrows indicate the corresponding lining in the real reactor part.

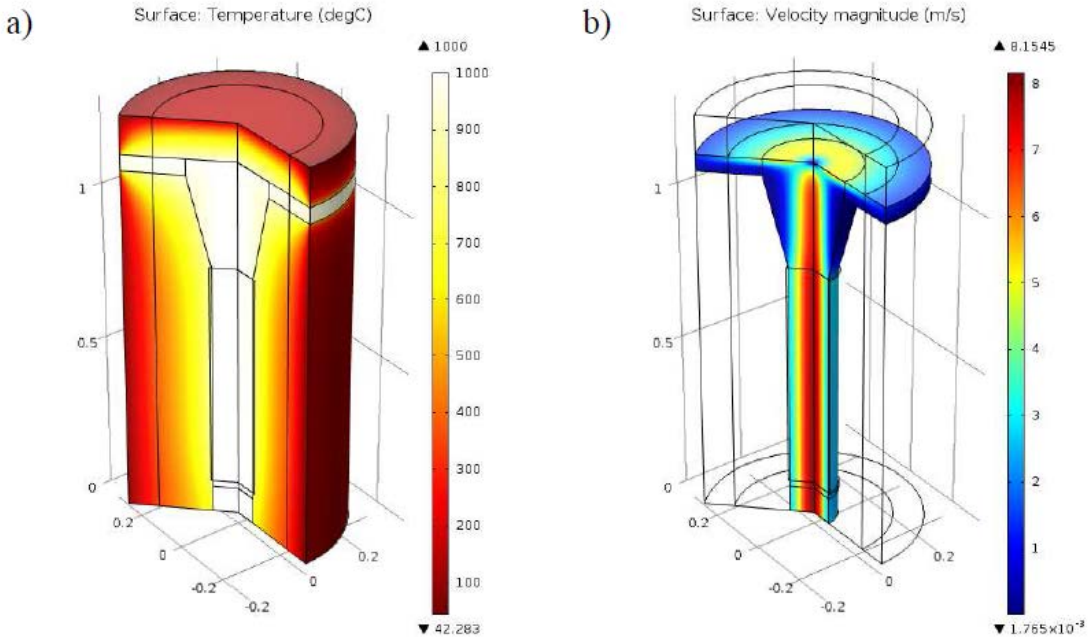


Figure 13: Thermal simulation of the reactor: (a) Insulating lining of the reactor; (b) Gas velocities for the fluidized bed.

Reactor integration into CSP plants

One of the most important parameters for the integration of a thermochemical reactor into a CSP plant is the outflow temperature of the heat transfer fluid (HTF). A summary of the attainable HTF outflow temperatures during charging of some potential reactor concepts is shown in Figure 14.

Circulating fluidized beds, or fluidized beds operated as a batch, inherently lead to a coupling of outflow temperature during charging $T_{f,c,out}$ to $T_{endo,\ rxn}$, the temperature at which the endothermic reaction takes place. The HTF needs to enter the TCS at $T_{f,c,in} > T_{endo,rxn}$ to provide the required heat for the reaction, however, it cannot be cooled below the temperature of the solids $T_{endo,rxn}$ before it leaves the TCS. Thus, these two concepts are applicable to a serial configuration (solar receiver => tc storage => power block) only. Note that moving beds with co-current flow of the gas and solid phases (not shown in Figure 14) would behave similar to the circulating fluidized bed.

By contrast, a packed bed can be operated such that the HTF is cooled to $T_{f,c,out} \sim T_{f,d,in}$ (inlet temperature during discharging) during charging as long as corresponding axial gradients in the solid's temperature are maintained; however, at some instant of time the HTF outflow temperature would start to increase continuously, which would not be suitable to any integration configurations. Therefore, a packed bed would only make sense to be implemented in a parallel configuration, and the charging process would need to be interrupted once the HTF outflow temperature starts to increase significantly.

The remaining reactor concepts shown in Figure 14 (multistage fluidized bed and moving beds with counter- or cross-current flow of the gas and solid phases) offer the possibility to maintain a constant HTF outflow temperature during charging, which can even be adjusted to a certain degree by appropriate reactor design and variation of the mass flow rates of the two phases. Thus, these reactor concepts could potentially be implemented as both parallel and serial configurations with respect to the power block. However, maintaining the desired outflow temperatures may become challenging once the charging power varies with time.

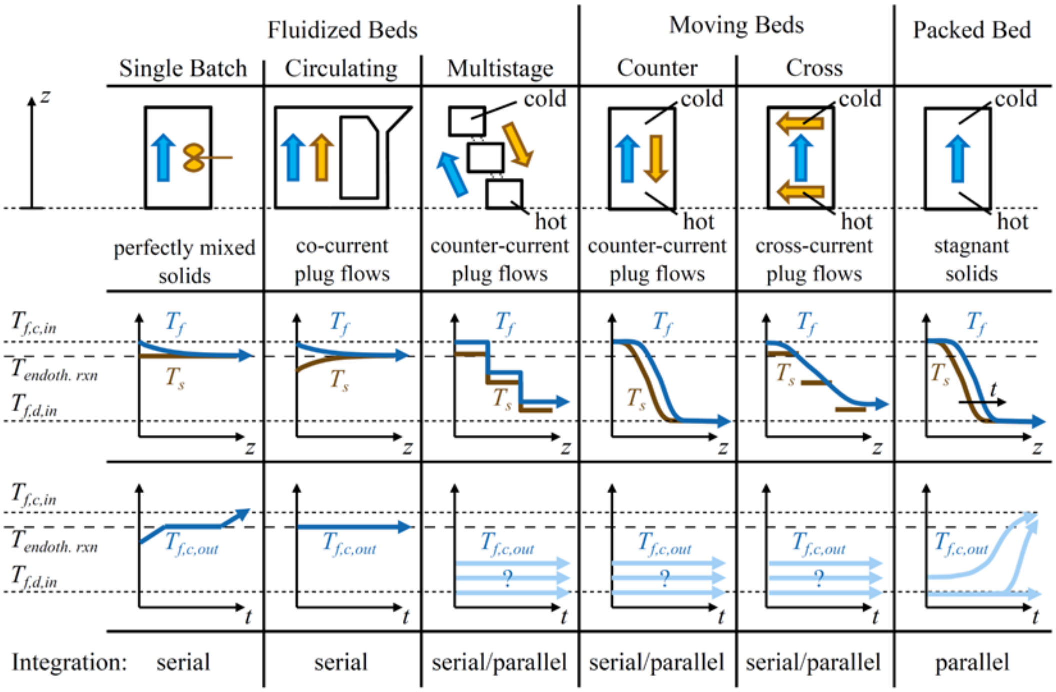


Figure 14: Summary of attainable HTF outflow temperatures in some potential gas-solid TCS reactor concepts. Note that in this figure, a direct contacting of the HTF and solid phases is indicated. However, the general behaviour of reactors with indirect contacting is similar.

Reactor concept for pilot plant system

According to the material properties as well as the integration possibilities described above, three different reactor designs for the pilot plant system have been proposed (Figure 15). All of them are indirectly operated counter-current moving bed reactors. One of the major disadvantages of the first reactor design is the rectangular shell geometry. In particular this shell geometry demands thick walls and stiffeners to withstand the operating pressure range from 0.1 – 2 bar. Additionally the flanges at the top and the bottom will be difficult to seal. To overcome this disadvantages one option is to place the rectangular heat exchange structure in a cylindrical shell (middle). The result is a compact reactor in a standard pressure vessel. Easy handling, moderate flange connections and a minimum amount of required steel are advantages which favour this concept.

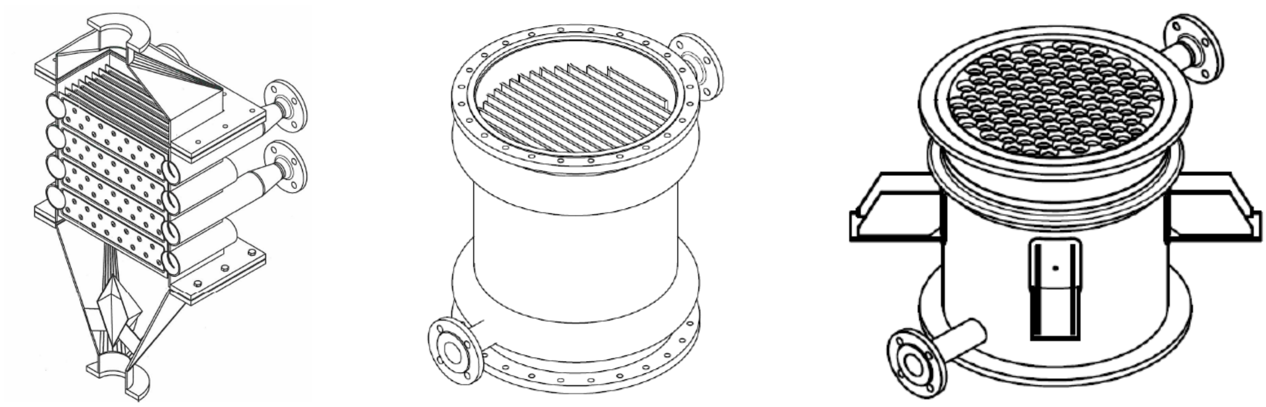


Figure 15: Proposed reactor designs for pilot plant system

Nevertheless, the rectangular heat exchanger geometry also brings some challenges for the control of the reaction process. First: if the material flow stops in only one gap due to bridging of the particles, the reactor power drops 10% (assuming 10 gaps in the reactor). Second: if channels occur in the material bulk, the reaction gas will only flow within these channels. As a consequence the reaction gas is distributed inhomogeneously within the reactor. In the worst case, when only a few large gas channels occur in the bulk, major amounts of the material further away from the gas channels will not come into contact with the reaction gas. Hence the reactor power is reduced to a minimum. Third: as it could be seen from the material flow pre-tests in an acrylic glass reactor it is difficult to reach a homogenous material flow within the gap. In the cold tests this was only possible by means of an additional rotating spline shaft.
To overcome the risks and challenges related to the rectangular heat exchange structure (first and second reactor design), a third reactor geometry has been considered (right): A cylindrical shell and tube heat exchanger. This concept combines a cylindrical pressure vessel on one hand and many separated tubes for the storage material on the other hand. The separated tubes bring the advantage that even if the material flow is blocked in some tubes the power decrease will be less significant compared to a blocked rectangular gap. In the same way the design is advantageous for the reaction gas transport. If gas channels occur in the tubes the inner diameter of the tubes limits the furthest distance to a particle. Hence if the diameter is chosen small enough the particles will still come in contact with the reaction gas. Even in the worst case if no reaction gas flows through one or more tubes the loss in power due to some inactive tubes is smaller compared to an inactive gap (160 tubes compared to 10 gaps). In addition, the pre-tests with a cold reactor showed that a homogenous flow through the tubes is achievable even without additional moving big blasters at the tube outlet. At last the shell and tube concept is a well know and up-scalable heat exchanger design.
With regard to the above discussed advantages BUHL and DLR decided to develop the pilot-reactor based on a shell and tube heat exchanger concept.

WP4 Lab-scale Testing

Lab-scale testing was actually done within WP4 for both reaction systems in parallel. Due to the decision taken during the mid-term review, to continue with both reaction systems till the end of the project, this section focuses only on the manganese oxide system developed by IMDEA Energy within WP4.

An experimental test bench for thermochemical characterisation of the TCS unit was designed and built in WP4.1 (see Figure 16). Given the challenges linked to materials and temperatures, lab-scale reactor selected for manganese oxide was a multipurpose system able to operate from fixed to fluidised bed conditions. It was expected that outcomes from this device provide useful information for pilot-scale facilities. The core part – the lab-scale reactor - offers the possibility to vary temperature, pressure and feed flow to the reactor. The test-bench itself is equipped with temperature and pressure sensors to collect data for validation of the simulation models and was used for experimental characterization of the developed reactor and the execution of experimental tests that combine various particle regimes from fixed to fluidized conditions and using inert materials, manganese oxide and doped manganese oxide. Figure 17 shows the pressure drop in the reactor as a function of the air mass flow rate using hot air at 650 ºC and 1000 ºC. Pressure drop was determined by decreasing the flow rate from its maximum in order to avoid initial particles inertia. As seen in the Figure, there are two ranges of flow rates where the particle regime is unique and independent of the temperature interval chosen. Operation at flow rates lower than 20 Nm^3/h ensures fixed bed mode, whilst flow rates higher than 45 Nm^3/h allows fluidization.

Figure 16: Test bench (left) and lab-scale reactor (right) for manganese oxide system

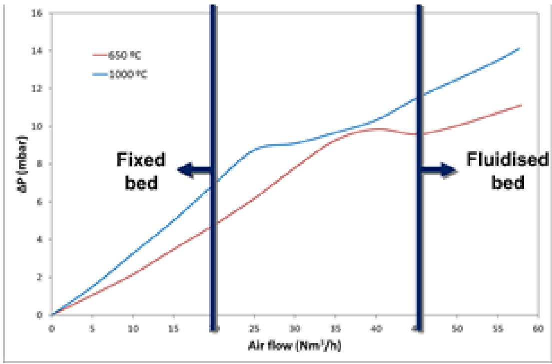


Figure 17: Characterization of the reactor with various particle regimes from fixed to fluidized conditions

Once the experimental methodology was established using inert material, the fluidization regime was determined for manganese oxide pellets varying the airflow rate and the inlet air temperature in the reactor. In the experimental tests with manganese oxide for doped and un-doped materials, chemical reaction has been monitored through measurements of temperature in the reaction zone and oxygen concentration in the outlet gas stream. The stability and degradation of the reacting materials has been analysed in tests composed of 25 consecutive thermal cycles under fixed and fluidized bed mode for the manganese oxide (compare Figure 18) and fixed bed operation for the Fe-doped manganese oxide.

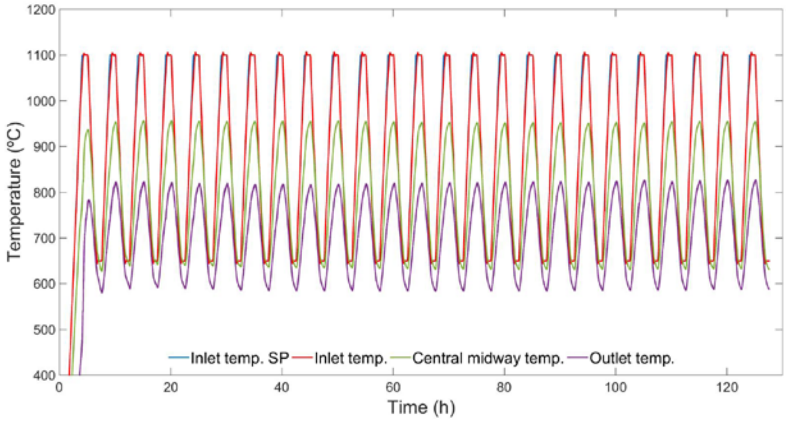


Figure 18: Temperature evolution during a long-duration test using manganese oxide pellets in fluidised bed conditions

The main conclusions obtained from experiments in lab-scale with manganese oxide granules are:

- Reactive material presents more attrition when it is tested in fluidization regime than in packed or fixed bed configuration;
- Material processed in fluidized bed regime shows signs of having been subjected to higher temperatures, even though the cycling temperature in fluidized and fixed bed experiments was the same. This is due to higher heat transfer in fluidised regime compared to packed bed mode. On the other hand, manganese oxide tested in fixed bed mode shows signs of having been subjected to axial temperature gradients in the bed.
- Analyses on reactant morphology, size and mechanical strength indicate that pellets suffered sintering and attrition during the performed essays, confirming the results obtained by thermal heat treatment of pellets combining oven and thermogravimeter and crush test.
- Chemical reactivity of manganese oxides continuously diminished until it disappeared within a few cycles for both fluidized and fixed bed regimes. Its hardness increasd with the number of cycles, reducing attrition. Fe-doped manganese oxide was tested in fixed bed regime for 25 cycles demonstrating its cyclability. This material also presents sintering and hardness diminution. Since these findings are somehow contradictory to the cycling experiments of manganese granules in the TGA, further research on the aspect of cyclability in small and lab-scale samples is required.

WP5 Pilot-scale Testing

The pilot-scale reactor unit was designed and fabricated by BUHL in cooperation with DLR in WP5.1. The main aspect was the compatibility with the thermochemical storage material and the adaptation of the reactor for an operation under the requirements of the TCSPower project. A drawing of the main parts of the pilot scale reactor is shown in Figure 19.

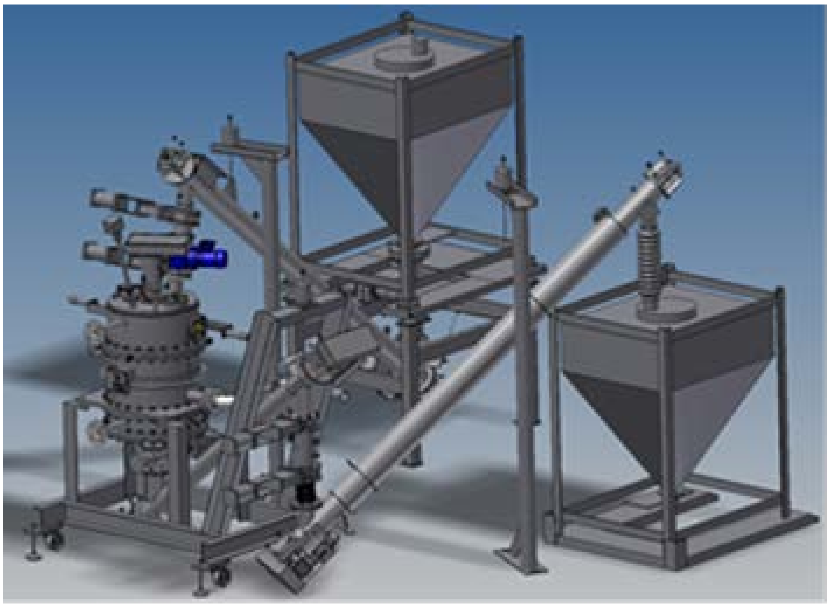


Figure 19: Drawing of the pilot scale reactor with required material handling

The reactor unit was integrated into the test facility at DLR, debugged stepwise and commissioned by DLR. Once the mechanical installations were finished all electrical connections between the motors and heating jackets and the control cabinet were established. Additional gas connections like the nitrogen purging for the screw conveyers and gas locks were installed. Pneumatic air had to be connected to the flaps of the gas locks. A picture of the pilot scale unit integrated into the test facility without insulation is shown in Figure 20.

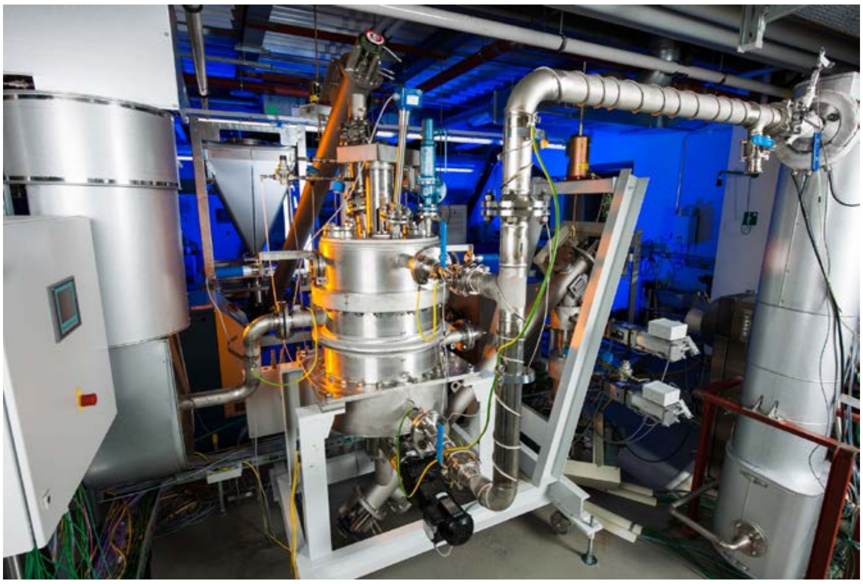


Figure 20: Picture of the integrated pilot scale reactor (reactor in front without insulation)

After all installations were finalized, the functionality of every component was tested. For this purpose the reactor was initially tested with calcium carbonate as an inert material. The particles had a size between 0,1 - 0,3 mm; thus a bulk of these particles shows a good flowability. At first 350kg of the material where filled into the storage silo and the silo then was coupled to the pilot reactor in order to test following aspects:

- Function and controllability of the heating jackets
- Correct movement of all screw conveyers
- Adjustability of the speed of the rotary valves in the desired range
- Free rotation of the scraper in the reactor
- Movement of the flaps
- Function of all purging gas valves
- Verification of the values of the temperature, pressure, weight and level sensors
- Gas tightness of the reactor and the pressure locks

In order to evaluate the performance of the heat exchanger the heat transfer from the material to the heat transfer fluid was tested. For this experiment a constant material mass flow through the reactor was adjusted. In this case the material drops into the reactor and flows inside the tubes. In order to observe the material temperature in the tubes, temperature sensors were placed every 100 mm along one tube in the middle of the tube bundle. The thermal performance was investigated with the inert material as well as with the reactive material developed within WP2. In all experiments a continuous flow of the material – under cold and hot conditions was achieved and the reactor showed the expected heat exchanger performance.

At the end of the project, experiments with chemical reactions were performed. In this case the temperature and pressure conditions were more severe in order to reach the reactive conditions of the material. As it can be seen in Figure 21, as soon as the pressure in the reactor drops, the material temperatures decrease. This correlation between decreasing pressure in the reactor and an observable decrease of the material temperature clearly indicates the ongoing endothermal reaction. However, due to leakage problems with the core part of the reactor, the experimental investigation has not been finalized and is ongoing – also after the end of the project.

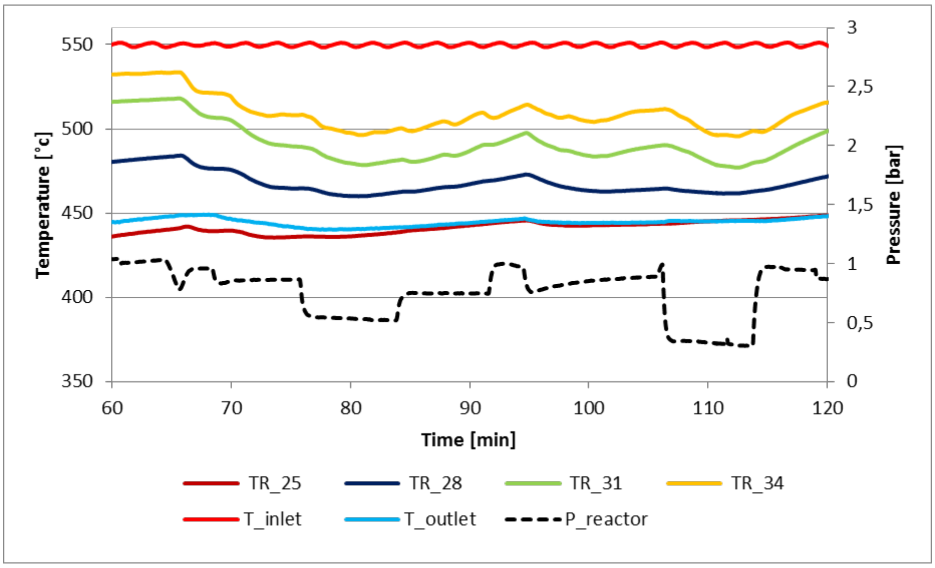


Figure 21: Experimental results obtained with the pilot scale reactor – case of dehydration

Within WP5 of the project the pilot plant with moving reactive powder has been developed and was successfully commissioned and set into operation. All single components have been tested successfully as well as the operation of the overall set up. The investigation of the material flow through the pilot plant was successful for an inert material as well as for the modified calcium hydroxide under hot and cold conditions. Additionally, the heat exchanger performance has been successfully tested. Based on the experiments with chemical reactions towards the end of the project, it could be shown that the material flows through the reactor under reaction conditions at 550°C and the presence of water vapour is possible. However, the experimental investigation of the pilot scale reactor has not been finalized till the end of the project. The most important aspects are related to the controllability of the reaction by means of a reaction gas pressure adjustment as well as the influence of the gas inlet on the flowability of the reacting powder.

WP6 Process Evaluation

The process evaluation in WP6 included the development of a simulation tool which allows an evaluation of the overall CSP plant performance. These investigations were closely interlinked with development WPs 2, 3 and 4. The up-scaling strategies for the investigated TCS systems to meet required storage capacities for commercial application was developed by the industrial partners (BUHL and SAG) taking plant layout, HTF system, charging/discharging modes of operation, integration into the plant control system as well as plant operation and maintenance (O&M) and commissioning strategies into account. Finally, a techno-economic evaluation of the TCS technology was performed. Therefore, in order to estimate the levelized cost of electricity (LCOE) in a CSP plant with implementation of a TCS system an economical evaluation model was developed based on the analysis of annual production results for CSP plant operation with TCS systems.

TCS Integration into CSP plant

Detailed thermodynamic models on a system level for the overall CSP plant for both reaction systems (calcium oxide and manganese oxide) and receiver technologies (external tube solar tower receiver and open volumetric receiver) were created. For these models the software ChemCAD Dynamics was used. Simulations were performed using the calculated solar field performance by DLR using weather data for three different locations in Spain, USA and Chile. The start-up and shut-down of the solar field depending on the available weather data was taken into account. The thermo-chemical storage was simulated using a Gibbs reactor and storage tanks. The specifications and results of these reactor simulations were discussed in detail with all consortium partners, especially IMDEA, RHM and PSI. For the steam cycle detailed simulations of an advanced three pressure level steam cycle with air cooled condenser were performed. The influence of the ambient temperature on the performance of the steam cycle was also part of the simulation. All simulations were made in dynamic mode, which reproduce the charging and discharging of the storage with the goal to achieve constant power output of the steam cycle.

The results of the simulations are shown in Figure 16, exemplary for the manganese oxide system and all three chosen locations.

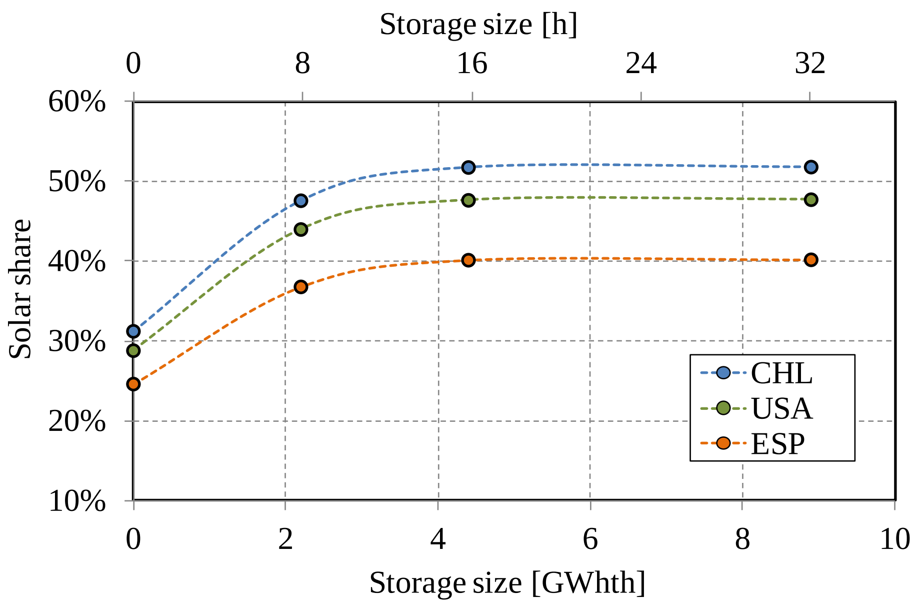


Figure 22: Solar share of the CPS plant for manganese oxide system

Upscaling strategies

In general the TCSPower system consists of three different parts – the solar field, the storage system and the steam cycle. These three parts have different maturities and thus different uncertainties during the up-scaling.

- Steam cycle
  The most mature part is the steam cycle. The power block is state of technology, there are already available turbines on the market and there are even references of such power blocks with the desired power.

- Solar field
  In case of the solar field the solar tower technology is available for the desired power. Nevertheless there are some limitations on the maximal power which can be covered by one tower. Especially for regions with bad atmospheric conditions multiple-tower concepts might be needed.
- Storage system
  The storage system has the highest uncertainty during up-scaling. For the reactor concepts that have been developed in the project, scale-up strategies have been worked out and showstoppers have been identified.
  However, the reactor concepts are still in the phase of experimental validation and continuous optimization (CaO – DLR, Cologne | Manganese – IMDEA, Madrid).

For better illustration both system concepts are shown in Figure 17.

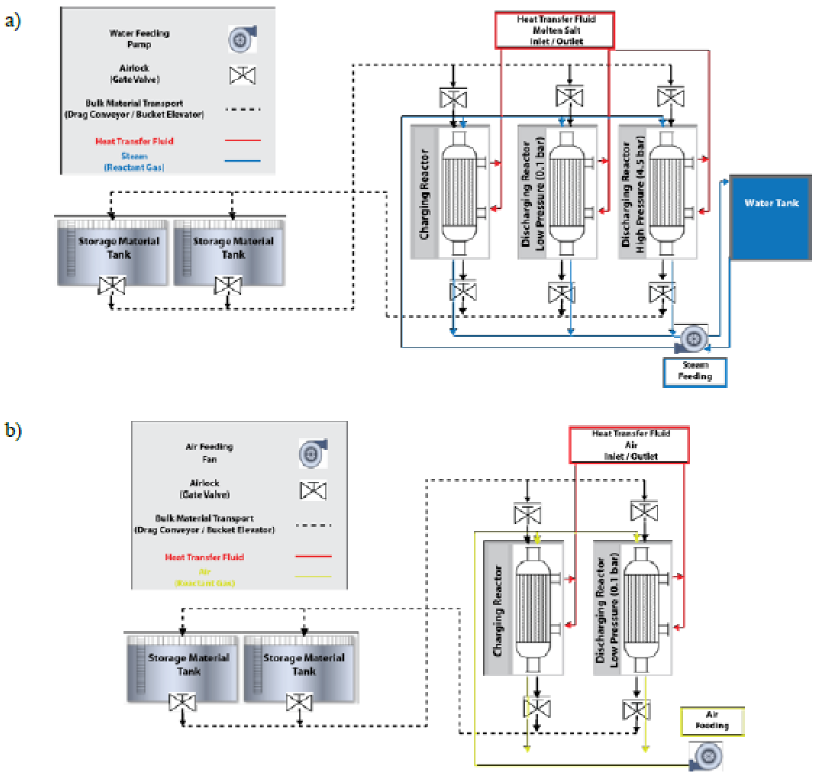


Figure 23: Thermal energy storage systems: a) calcium oxide system; b) manganese oxide system

Based on these system concepts a list of components and their expected costs was used for further economical evaluation. Except for the reactor all components are based on commercially available technologies. The highest risk is the reactor system since it is obviously still in the phase of experimental validation.

Techno-economic evaluation

The most significant result from this task was the levelized cost of electricity (LCOE) for both reaction systems and the three locations (see Figure 18) and the specific cost of the thermal storage.

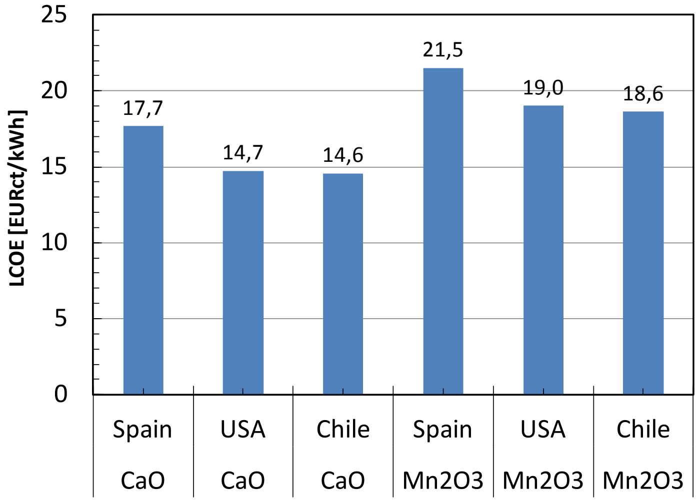
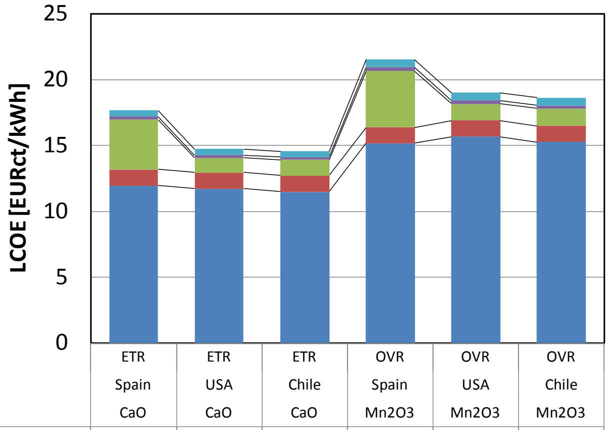


Figure 24: LCOE for both reaction systems and the different locations

A direct LCOE comparison with other values listed in the literature is only possible if all boundary conditions are comparable. Nevertheless the calculated LCOE of the calcium oxide system are in the same order of magnitude compared to values for solar tower power plant with molten salt thermal storage – 16,5$-cent/kWh.

The difference of the LCOE for the different locations is caused mainly by the difference of the estimated solar share and gas price: 8,33€/GJ for Spain, 2,78€/GJ for USA and 3,2€/GJ for Chile (see Figure 19).



	ETR Spain CaO	ETR USA CaO	ETR Chile CaO	OVR Spain Mn2O3	OVR USA Mn2O3	OVR Chile Mn2O3
Decommissioning	0,46	0,45	0,44	0,58	0,60	0,59
CO2 tax	0,25	0,22	0,21	0,28	0,25	0,23
Gas cost	3,78	1,12	1,21	4,27	1,26	1,32
O & M cost	1,22	1,22	1,22	1,22	1,22	1,22
CAPEX	11,95	11,72	11,49	15,16	15,68	15,28

Figure 25: Comparison of LCOE for the different technologies and locations (ETR: external tube receiver; OVR: open volumetric receiver)

From the figure above it is obvious that the CSP plant with external tube receiver and calcium oxide system has lower LCOE for all locations compared to the open receiver tower with manganese oxide system. This is the case because of the much higher cost for the open receiver tower system while the cost of the thermal storage itself has comparable cost for both reaction systems.

In order to make direct comparison of the tow storage technologies the costs for the thermal storage only were compared. In most literature references the cost of storage systems are presented without balance of plant, civil works, etc. This corresponds in our case to the bare erected cost of the main components of the storage (BEC without BoP, improvements of site, etc.). The calculated cost of the storage is 61,5 €/kWhth and 64,5 €/kWhth for the calcium oxide storage and manganese oxide, respectively. These values are comparable and slightly higher compared to molten salt storage in parabolic through solar reciever – 55 €/kWhth. Compared to a molten salt storage used in combination with a molten salt solar tower (25 €/kWhth) the cost is much higher. This is the case because of the fact that in this case the heat exchanger needed for the storage is part of the solar tower and not of the storage. Thus the cost for it is not counted as part of the storage cost. In the TCSPower case the capacity of the storage is decoupled from the power of the storage. Thus, increasing the capacity of the storage can decrease the specific cost. In order to illustrate this issue the BEC of the main components for both storage technologies were calculated for different storage capacities. The assumption was made that all components related to the storage power (reactor system, transport system, etc.) keep its costs and all components related to the capacity (storage tanks) change its cost linearly with the capacity (see Figure 20).

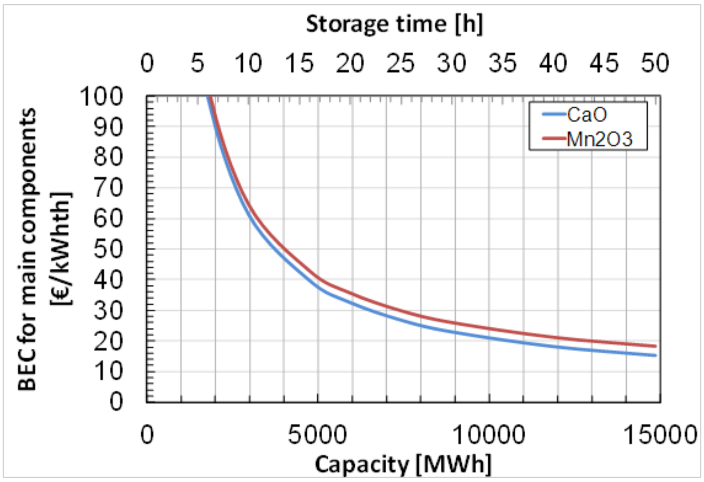


Figure 26: BEC of the thermal storage for both storage technologies as a function of the storage capacity

According to the results from the system simulations, an optimal storage capacity for the TCS plant is around 10 hours or about 3000MWh$_{th}$. Increasing the capacity of the storage decreases the specific costs. It is obvious that the most cost decrease takes place up to a storage size of about 10000 MWh$_{th}$ – 20€/kW$_{th}$. For this working point calculations for the TCS plant were performed and show no advantage compared to the 10h storage. Nevertheless this sensitivity study shows that theoretically - if there is a use case available for thermal storages with higher capacity - one can reach a cost level of about 20€/kWh$_{th}$.

As a consequence, future research in the field of thermochemical energy storage for CSP has to address the complexity of the overall system. For instance, the above mentioned configuration for the calcium oxide system actually uses molten salt as HTF, the thermochemical reaction to store the thermal energy as well as water vapour as working fluid of the power block. However, due to the possibility to move the material, one development direction could be to utilize the thermochemical material as both: as heat transfer fluid and as thermal energy storage. In this case the design of the CSP plant with TCS cannot be based on a molten salt reference configuration but the amount of costly heat exchangers/reactors could be clearly reduced. Additionally, an important outcome of the techno-economic evaluation is that even if material modifications increase the cost for the storage material, it can be clearly beneficial if at the same time the reactor and system complexity can be reduced.

Conclusions and potential impacts, including the socio-economic impact and the wider societal implications of the project

- Two materials suitable for thermochemical energy storage at high temperatures have been investigated and the results have been published.
- Manufacturing route for large scale production of MnO with improved cyclability has been developed and its impact on the material performance evaluated. These results may be of significant economic impact.
- The addition of nano-structured particles in order to enhance material properties, e.g. flowability has been investigated - for the first time related to thermochemical energy storage.
- Two reactor concepts with – in principle – infinite storage capacity have been identified as suitable for thermochemical energy storage and experimentally investigated according to their current state of development.
- The material handling of reactive fine powder has been addressed within the project. The experimental results as well as the experimental experience may have economic impact for industries active in the field of powder handling at lower temperatures.
- The possibility to store and to upgrade thermal energy at high temperature levels has been investigated. These results may be of significant economic impact – potentially in the field of conventional power plants.
- The demonstrated possibly to store thermal energy – in large scale with minor losses – may have significant impact on the energy system, not only in the field of CSP.

Exploitation of results

- The developed thermochemical energy storages are in principle independent from the reaction system. Even though specific material properties have to be taken into account, the two developed reactor concepts can be used at different temperature levels – e.g. for solar process heat.
- The first-of-its-kind pilot scale reactor for calcium oxide will be investigated for utilization in various energy-related applications, such as power-to-heat, industrial waste heat recovery or conventional power plants.
- The possibility of enhancing material properties of reactive fine powders by the addition of nano-structured powders will be transferred to other scientific areas.
- According to the techno-economic evaluation, the main drawback of the developed integration strategy is the necessity of more than one heat transfer fluid. Future development of the thermochemical storage will therefore address the possibility to utilize the storage material as heat transfer fluid thereby reducing the required heat exchangers.
- According to the techno-economic evaluation at the end of the project, the storage duration has an enormous impact on the economic feasibility. On the other hand, thermochemical storages have the potential to store thermal energy for longer periods. In combination with the developed concept of detached power and capacity, this technology could lead to technologies that offer dispatchable renewable power – for more than 24 hours.
- Besides the below mentioned publications, the scientific results will be used for education, e.g in the frame work of lectures and theses.

Main dissemination activities

Activity type	Description of activities/achievements
Horizontal activities	
Training and education	6 PhD students and 2 PostDocs involved in the project
Public awareness	Papers, Conferences, Workshop, Homepage
Dissemination	
Conference presentations	1. J. Moya, A. Bayón, P. Jana, M. Romero, J. González Aguilar, V. de la Peña O'Shea, D. P. Serrano and J. M. Coronado, Influence of the Synthesis Method on the Energy Storage Capacity of Mn2-xCoxO3 Materials, Innostock 2012, The 12th International Conference on Energy Storage. Lleida, Spain. 2012 (Poster) 2. A. J. Carrillo, J. Moya, A. Bayón, P. Jana, V. A. de la Peña O'Shea, M. Romero, J. Gonzalez-Aguilar, P. Pizarro, D. P. Serrano and J. M. Coronado, Thermochemical Energy Storage at High Temperature via Redox Cycles of Mn-Co Mixed Oxides. EnMat II: 2nd International Conference on Materials for Energy. Karlsruhe, Germany. May 12-16th, 2013. (Poster) 3. A. J. Carrillo, S. Alvarez, D. P. Serrano, M. Romero, J. Gonzalez-Aguilar, P. Pizarro and J. M. Coronado, Manganese oxide based thermochemical heat storage for CSP: Influence of synthesis parameters on the materials cyclability. EuroMat 2013: European Congress and Exhibition on Advanced Materials and Processes. Seville, Spain. September 9-13th, 2013. (Oral) 4. A. J. Carrillo, D. P. Serrano, P. Pizarro and J. M. Coronado, Improving the Performance of Thermochemical Heat Storage at High Temperatures Based on Redox Metal Oxides, Eurotherm Seminar 99: Advances in Thermal Energy Storage, Lleida, Spain. May 28-30th, 2014. 5. S. Álvarez de Miguel, J. Gonzalez-Aguilar, M. Romero, 100-Wh multi-purpose particle reactor for thermochemical heat storage in concentrating solar power plants, SolarPACES 2013, Las vegas, NV, EEUU. September 17-20, 2013 6. A. J. Carrillo, D. P. Serrano, P. Pizarro, J. M. Coronado, Thermochemical heat storage at high temperatures using Mn2O3/Mn3O4 system: narrowing the redox hysteresis by metal co doping, International Renewable Energy Storage Conference 2015, Düsseldorf, Germany. March 9-11th, 2015 (Oral) 7. A. J. Carrillo, D. P. Serrano, P. Pizarro, J. M. Coronado, Design of Efficient Mn-based Redox Materials for Thermochemical Heat Storage at High Temperatures, SolarPACES 2015, Cape Town, South Africa. October 13-16th, 2015 (Oral) 8. S. Álvarez de Miguel , S. Bellan, J.M. García de María, J. González-Aguilar, M. Romero, Numerical Modelling of a 100-Wh Lab-Scale Thermochemical Heat Storage System for Concentrating Solar Power Plants, SolarPACES 2015, Cape Town, South Africa. October 13-16th, 2015 (Poster)

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10. S. Ströhle, Sollab Doctoral Colloquium, Hornberg, Germany, 13-14/05/2013 (oral presentation)
11. S. Ströhle, ASME Summer Heat Transfer Conference, Minneapolis, USA, 14-19/07/2013 (oral presentation and conference paper)
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Workshops organized by the project	1. TCS Collaborative Workshop Organized by TCSPower together with StorrE and Restructure. In Cologne, Sept. 2015, Around 45 Participants
Publications and Patents	
Publications	1. A.J. Carrillo, D.P. Serrano, P. Pizarro, J.M. Coronado, Thermochemical heat storage based on the Mn2O3/Mn3O4 redox

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6. Roßkopf, C. und Haas, M. und Faik, A. und Linder, M. und Wörner, A. (2014) Improving Powder Bed Properties for Thermochemical Storage by Adding Nanoparticles. Energy Conversion and Management, 86, Seiten 93-98. DOI:http://dx.doi.org/10.1016/j.enconman.2014.05.017. ISSN 0196-8904.
7. Linder, Marc und Roßkopf, Christian und Schmidt, Matthias und Wörner, Antje (2014) Thermochemical Energy Storage in kW-scale based on CaO/Ca(OH)2. Energy Procedia (49), Seiten 888-897. Elsevier. DOI: 10.1016/j.egypro.2014.03.096. ISSN 1876-6102.
8. Shao, H. und Nagel, T. und Roßkopf, C. und Linder, M. und Wörner, A. und Kolditz , O. (2013) Non-equilibrium thermo-chemical heat storage in porous media: Part 2 – A 1D computational model for a calcium hydroxide reaction system. Energy. ISSN 0360-5442.
9. Roßkopf, Christian und Afflerbach, Sandra und Schmidt, Matthias und Görtz, Burkhard und Torsten, Kowald und Linder, Marc und Reinhard, Trettin (2015) Investigations of nano coated calcium hydroxide cycled in a thermochemical heat storage. Energy Conversion and Management (97), Seiten 94-102. Elsevier. DOI: 10.1016/j.enconman.2015.03.034. ISSN 0196-8904.
10. A.J. Carrillo, J. Moya, A. Bayón, P. Jana, V.A. de la Peña O'Shea, M. Romero, J. Gonzalez-Aguilar, D.P. Serrano, P. Pizarro, J.M. Coronado, Thermochemical energy storage at high temperature via redox cycles of Mn and Co oxides: Pure oxides versus mixed ones, Sol. Energy Mater. Sol. Cells. 123 (2014) 47–57. doi:10.1016/j.solmat.2013.12.018.
11. A.J. Carrillo, D.P. Serrano, P. Pizarro, J.M. Coronado, Thermochemical heat storage at high temperatures using

	Mn2O3/Mn3O4 system: narrowing the redox hysteresis by metal co-doping, Energy Procedia 73 (2015) 263-271 doi: 10.1016/j.egypro.2015.07.686 12. Ströhle, S., Haselbacher, A., Jovanovic, Z., & Steinfeld, A. (2014). Transient discrete-granule packed-bed reactor model for thermochemical energy storage. Chemical Engineering Science, 117, 465–478. 13. Ströhle, S., Haselbacher, A., Jovanovic, Z., & Steinfeld, A. The Effect of Gas-Solid Contacting Patterns on the Performance of High-Temperature Thermochemical Storage in CSP Plants (Manuscript in preparation). 14. S. Álvarez de Miguel, G. Mollocana, C. E. García, M. Romero, J.M. García de María and José González-Aguilar, Identification Model and PI & PID-Controller Design for a Novel Three-Phase Electric Air Heater, Journal of Control Engineering and Applied Informatics (submited) 15. A.J. Carrillo, D.P. Serrano, P. Pizarro, J.M. Coronado, Design of Efficient Mn-based Redox Materials for Thermochemical Heat Storage at High Temperatures. (submitted to AIP Conference Proceedings) 16. S. Álvarez de Miguel, J.-B. Soupart, J. González-Aguilar, M. Romero, Performance of Manganese Oxides Granules for Thermochemical applications (in preparation). 17. S. Álvarez de Miguel, A.J. Carrillo, J.-B. Soupart, P. Pizarro, J. González-Aguilar, J.M. Coronado, M. Romero, D. P. Serrano, Oxidation reaction kinetics for manganese oxides in thermochemical storage applications (in preparation)
Patents	1. Verfahren zum Betrieb eines thermochemischen Wärmespeichers, Siemens, V. Danov M. Kautz 2. High Temperature Reversible Oxygen Carrier and Method for its Production, ERACHEM-Comilog, J-B. Soupart

Relevant contact details

Full project title	Thermochemical Energy Storage for Concentrated Solar Power Plants
Project acronym	TCSPower
Call	ENERGY.2011.2.5-1
Grant agreement number	282889
Coordinator organization/Affiliation	Dr.-Ing. Marc Linder German Aerospace Center (DLR) Institute of Engineering Thermodynamics Pfaffenwaldring 38-40 70569 Stuttgart Germany +49 711 68628034

	marc.linder@dlr.de
Project start-date	01/11/2011
Project end-date	31/07/2015

Partner number	**Partner Name**	**Industry or Research**	**Country**	**Comments**
1.	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Research	Germany	Coordination
2.	SIEMENS CONCENTRATED SOLAR POWER LTD	Industry	Israel	Project exit in month 12
3.	BUHLER AG	Industry	Switzerland	
4.	ERAMET & COMILOG CHEMICALS SA	Industry	Belgium	
5.	Fundacion IMDEA Energia	Research	Spain	
6.	PAUL SCHERRER INSTITUT	Research	Switzerland	
7.	UNIVERSITAET SIEGEN	Research	Germany	
8.	SIEMENS AG	Industry	Germany	Project entry month 24

4.2 Use and dissemination of foreground

Section A (public)

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	Thermochemical energy storage at high temperature via redox cycles of Mn and Co oxides: Pure oxides versus mixed ones	A. J. Carrillo	Solar Energy Mater. Solar. Cells	123	Elsevier		2014	47–57	doi:10.1016/j.solmat.2013.12.018	no
2	Improving the Thermochemical Energy Storage Performance of the Mn_2O_3/Mn_3O_4 Redox Couple by the Incorporation of Iron.	A.J. Carrillo	Chem. Sus. Chem.	8	Wiley		2015	1947–1954	doi:10.1002/cssc.201500014	no
3	Thermochemical heat storage based on the Mn_2O_3/Mn_3O_4 redox couple: influence of the initial particle size on the morphological evolution and cyclability,	A.J. Carrillo	J. Mater. Chem. A	2	RSC		2014	19435–19443	doi:10.1039/C4TA03409K	no

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).
[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

4	Thermochemical heat storage at high temperatures using Mn_2O_3/Mn_3O_4 system: narrowing the redox hysteresis by metal co-doping,	A.J. Carrillo	Energy Procedia	73	Elsevier		2015	263-271	doi: 10.1016/j.egypro.2015.07.686	Yes
5	100-Wh multi-purpose particle reactor for thermochemical heat storage in concentrating solar power plants	S. Álvarez de Miguel,	Energy Procedia	49	Elsevier		2014	676-683	DOI: 10.1016/j.egypro.2014.03.073	Yes
6	Identification Model and PI & PID-Controller Design for a Novel Three-Phase Electric Air Heater	S. Álvarez de Miguel	Journal of Control Engineering and Applied Informatics		STRAIT		(2015)		Submitted	No
7	Oxidation reaction kinetics for manganese oxides in thermochemical storage applications	S. Álvarez de Miguel	(Tentative journal, Industrial & Engineering Chemistry Research).		RSC		(2016)		In preparation	No
8	Analysis of Manganese Oxides Pellets for High-Temperature Thermochemical storage	S. Álvarez de Miguel,	(Tentative journal: Solar Energy).		Elsevier		(2016)		In preparation	No
9	Transient discrete-granule packed-bed reactor model for thermochemical energy storage	S. Ströhle	Chemical Engineering Science	No 117, September 2014	Elsevier	Netherlands (?)	2014	pp. 465-478	http://dx.doi.org/10.1016/j.ces.2014.07.009	no
10	The effect of gas-solid contacting patterns on the performance of high-temperature	S. Ströhle	Energy and Environmental Science				2015 (?)		submitted	no

	thermochemical storage in CSP plants									
11	Investigations of nano coated calcium hydroxide cycled in a thermochemical heat storage	C. Roßkopf, S. Afflerbach	J. Energ. Convers. Management.	No 97, January 2015	Elsevie r	Amsterd am	2015	pp. 94 - 102		no
12	Non-equilibrium thermochemical heat storage in porous media: Part 1 – Conceptual model.	Nagel, T. und Shao, H. und Watanabe, N. und Roßkopf, C. und Linder, M. und Wörner, A. und Kolditz , O.	Energy.				(2013)			
13	Non-equilibrium thermo-chemical heat storage in porous media: Part 2 – A 1D computational model for a calcium hydroxide reaction system.	Shao, H. und Nagel, T. und Roßkopf, C. und Linder, M. und Wörner, A. und Kolditz , O.	Energy.				(2013)		http://dx.doi.org/10.1016/j.applthermaleng.2013.09.020.	
14	Experimental results of a 10 kW high temperature thermochemical storage reactor based on calcium hydroxide. Seiten DOI:	Schmidt, Matthias und Szczukowski, Christoph und Roßkopf, Christian und Linder, Marc und Wörner, Antje	Applied Thermal Engineering (62),				(2013)	553-559.		
15	Improving Powder Bed Properties for Thermochemical Storage by Adding Nanoparticles.	Roßkopf, C. und Haas, M. und Faik, A. und Linder, M. und Wörner, A.	Energy Conversion and Management, 86				(2014)	93-98.	DOI:http://dx.doi.org/10.1016/j.enconman.2014.05.017.	
16	Thermochemical Energy Storage in kW-scale based on CaO/Ca(OH)2.	Linder, Marc und Roßkopf, Christian und Schmidt, Matthias und Wörner, Antje	Energy Procedia (49),		Elsevie r.		(2014)	888-897	DOI: 10.1016/j.egypro.2014.03.096.	
17	Integration strategies for Ca(OH)2 based	Schmidt, Matthias; Danov, Vladimir,							In preparation	

	thermochemical storages	Schäfer Jochen, Linder, Marc								
18	Experimental results of a thermochemical system based on Ca(OH)2 in pilot scale	Schmidt, Matthias; Giger, Franz; Gruen, Manfred; Hofer, Markus; Linder, Marc							In preparation	

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities[4]	Main leader	Title / Event	Date	Place	Type of audience[5]	Size of audience	Countries addressed
1	Conference	J.M. Coronado	Influence of the Synthesis Method on the Energy Storage Capacity of $Mn_{2-x}Co_xO_3$ Materials / INNOSTOCK 2012	May 2012	Lleida (Spain)	Scientific Community	200	International
2	Conference	A. J. Carrillo	Thermochemical Energy Storage at High Temperature via Redox Cycles of Mn-Co Mixed Oxides / International Conference on Materials for Energy	May 12-16th, 2013.	Karlsruhe, Germany	Scientific Community	500	International
3	Conference	A. J. Carrillo	Manganese oxide based thermochemical heat storage for CSP: Influence of synthesis parameters on the materials cyclability./ European Congress and Exhibition on Advanced Materials and Processes	September 9-13th, 2013	Seville, Spain	Scientific Community	500	International
4	Conference	J. Gonzalez-Aguilar	100-Wh multi-purpose particle reactor for thermochemical heat storage in concentrating solar power plants / SolarPaces 2013	September 17-20, 2013	Las Vegas, NV, EEUU	Scientific Community	500	International
5	Conference	A.J. Carrillo	Influence of the Synthesis Method on the Energy Storage Capacity of $Mn_{2-x}Co_xO_3$ Materials / Eurotherm Seminar Nº99: Advances in Thermal Energy Storage,	28-30th May 2014	Lleida (Spain)	Scientific Community	200	International
6	Exhibition GENERA 2015	S. Álvarez de Miguel	Almacenamiento termoquímico de energía en centrales solares termoeléctricas. Proyecto TCS Power	February 26, 2015	Madrid, Spain	General public	200	Spain

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias ('multiple choices' is possible.

7	Conference	A. J. Carrillo	Thermochemical heat storage at high temperatures using Mn_2O_3/Mn_3O_4 system: narrowing the redox hysteresis by metal co doping,/Energy Storage 2015	March 9-11th, 2015	Düsseldorf, Germany	Scientific Community, Industry	200	International
8	Conference	J. M. Coronado	Design of Efficient Mn-based Redox Materials for Thermochemical Heat Storage at High Temperatures / SolarPaces 2015	October 13-16th, 2015	Cape Town, South Africa	Scientific Community	500	International
9	Conference (presentation)	S. Ströhle	Sollab Doctoral Colloquium	25-26 June 2012	Almería, Spain	Scientific Community	50	European
10	Conference (presentation)	S. Ströhle	Sollab Doctoral Colloquium	13-14 May 2013	Hornberg, Germany	Scientific Community	55	European
11	Conference (presentation, paper)	S. Ströhle	ASME Summer Heat Transfer Conference	14-19 July 2013	Minneapolis, USA	Scientific Community	1000	International
12	Conference	C. Roßkopf, S. Afferbach	International Conference on Materials for Energy	May 2013	Karlsruhe, Germany	Scientific Community	80	International
13	Conference	S. Afflerbach	International Conference on Materials and Technology	Nov. 2013	Portoroz, Slovenia	Scientific Community	80	International
14	Workshop	S. Afflerbach	Collaborative Workshop	Sept. 2015	Cologne, Germany	Scientific Community	40	European
15	Conference	Schmidt, Patrick	Pilot Plant Development of High Temperature Thermochemical Heat Storage / INNOSTOCK 2012	15.-17. May 2012,	Lleida, Spain.	Scientific Community	200	International
16	Conference	Roßkopf, Christian	Optimierung der Reaktionsbetteigenschaften für thermochemische Energiespeiche/ ProcessNet Jahrestagunng	10.-13. Sep. 2012,	Karlsruhe, Germany	Scientific Community	100	National
17	Conference	Linder, Marc	Thermochemical heat storage based on the reaction system CaO/Ca(OH)2/SolarPaces 2012	11.-14. Sep. 2012	Marrakech, Marokko.	Scientific Community	100	International
18	Conference	Schmidt, Matthias	High Temperature Thermochemical Heat Storage - Experimental Results of a Pilot Reactor Based on CaO/Ca(OH)2/ International Renewable Energy Storage Conference and Exhibition IRES	12.-15. Nov. 2012,	Berlin. Germany	Scientific Community	150	International
19	Conference	Roßkopf, C	Modification of Fine-Grained Powder to Facilitate a Moving	September 9-13th,	Sevilla, Spain	Scientific Community	50	International

			Reaction Bed for Thermochemical Energy Storage / European Congress and Exhibition on Advanced Materials and Processes	2013				
20	Conference	Roßkopf, C.	Modified Materials for Thermochemical Energy Storage / 2nd International Conference on Materials for Energy,	2013	Karlsruhe, Germany	Scientific Community	100	International
21	Conference	Roßkopf, C.	Untersuchung und Optimierung von Fließ- und Durchströmungsverhalten von Schüttungen zur thermochemischen Wärmespeicherung / Jahrestagung für Agglomerations- und Schüttguttechnik,	2013	Wittenberg, Germany.	Scientific Community	150	National
22	Conference	Linder, Marc	Development of a Thermochemical Heat Storage Based on CaO/Ca(OH)2 / Eurotherm Seminar - Concentrating Solar Energy Systems. Eurotherm Seminar No. 98,	4.-5. July 2013,	Wien, Austria	Scientific Community	60	International
23	Conference	Linder, Marc	Thermochemical Energy Storage in kW-scale based on CaO/Ca(OH)2 / Solar PACES Conference	17.-20. Sept. 2013	Vegas, USA.	Scientific Community	100	International
24	Conference	Linder, Marc	Thermochemical Energy Storage based on Ca(OH)2 / 7th International Concentrated Solar Thermal Power Summit,	12.-13. Nov. 2013,	Sevilla, Spain	Scientific Community	200	International
25	Conference	Schmidt, Matthias	High temperature thermochemical heat storage: operation modes of a 10kW pilot reactor based on CaO/Ca(OH)2 / IRES 2013	18.-20. Nov. 2013	Berlin, Germany	Scientific Community	100	International
26	Conference	Roßkopf, C.	Improving Powder Flowability by Adding Nanoparticles for Thermochemical Heat Storage with Moving Reaction Bed / 7th World Conference on Particle Technology,	19.-22. May 2014,	Peking, China.	Scientific Community	150	International
27	Conference	Schmidt, Matthias	Operation modes and process integration of a thermochemical heat storage system based on	28.-30. May 2014,	Lleida, Spain	Scientific Community	100	International

			CaO/Ca(OH)2 / Eurotherm Seminar Nº99: Advances in Thermal Energy Storage,					
28	Conference	Schmidt, Matthias	Operation modes and process integration of a high temperature thermochemical heat storage system / Grand Renewable Energy 2014,	28. Jul. - 01. Aug. 2014,	Tokyo, Japan.	Scientific Community	100	International
29	Conference	Gollsch, Marie	Ansätze zur Verbesserung der Fließfähigkeit des thermochemischen Speichermaterials Ca(OH)2 / Jahrestreffen der Fachgruppe Agglomerations- und Schüttguttechnik,	16.-18. March 2015,	Magdeburg, Germany	Scientific Community	50	National
30	Conference	Linder, Marc	The TCSPower Project (Poster) / Greenstock 2015	19.-21. May 2015	Beijing, China	Scientific Community	200	International
31	Conference	Linder, Marc	The TCSPower Project (Poster) / SolarPaces 2015	13.-16. Oct 2015	Cape Town, South Africa	Scientific Community	300	International
32	Conference	Schmidt, Matthias	Development of a Moving Bed Pilot Plant for Thermochemical Energy Storage with CaO/Ca(OH)2 / SolarPaces 2015	13.-16. Oct 2015	Cape Town, South Africa	Scientific Community	100	International

Section B (Confidential[6] or public: confidential information to be marked clearly)
Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.

The list should, specify at least one unique identifier e.g. European Patent application reference. For patent applications, only if applicable, contributions to standards should be specified. This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.

Type of IP Rights[7]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
application for protection rights	yes	12.12.2014	Application no. 102014225696.8	Verfahren zum Betrieb eines thermochemischen Wärmespeichers	V. Danov M. Kautz
Provisional patent	No		US62127677	High Temperature Reversible Oxygen Carrier and Method for its Production	ERACHEM-Comilog

[6] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[7] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Please complete the table hereafter:

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge	Synthesis procedures to adjust the thermochemical properties of MnOx poweders	Yes		Improved TCS materials	C20, M72			IMDEA Energy, Erachem
General advancement of knowledge	Methodology for thermochemical storage materials characterisation	No		Thermal energy storage	C20, M72			IMDAE Energy, Erachem, DLR, Uni Siegen
General Advancement of knowledge	Control system software for high-temperature air heaters	Yes		Process control	C28.2, M72			IMDEA Energy
General Advancement of knowledge	Test bed for analysing themal energy storage perfomance at lab-scale	No		Thermal energy storage	C26.5, C28.2, M72			IMDEA Energy, DLR
General Advancement of knowledge	Use of fluidised bed in thermal energy storage	No		Thermal energy storage	M72			IMDEA Energy
General Advancement of knowledge	Use of fluidised bed in thermochemical energy storage	No		Thermal energy storage	M72			IMDEA Energy
Commercial exploitation of R&D results	High Temperature Reversible Oxygen Carrier	NO		DOPED MN OXIDE	C20.1.3		PATENT PENDING	ERACHEM-COMILOG

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.
[9] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	High Temperature Reversible Oxygen Carrier	NO		DOPED MN OXIDE IN A GRANULATED FORM	C20.1.3		PATENT PENDING	ERACHEM-COMILOG
General advancement of knowledge	Impact of gas-solid contacting patterns on integration of TCS into CSP plants	NO		STORAGE INTEGRATION	ENERGY			PSI/DLR/SIEMENS/IMDEA
General advancement of knowledge	Implication of TCS integration strategy on performance of CSP plant	NO		STORAGE INTEGRATION	ENERGY			SIEMENS/PSI/DLR /IMDEA
General advancement of knowledge	Changes of material properties during repeated thermochemical cycling Side reactions under cycling conditions	NO		MATERIAL HANDLING	ENERGY			SIEGEN/DLR
General advancement of knowledge	Pilot scale unit for high temperature thermochemical energy storage	NO		THERMAL ENERGY STORAGE WITH HIGH ENERGY DENSITY	ENERGY			DLR/BUHL
General advancement of knowledge	Detachment of power and capacity for tc storages at pilot scale	NO		THERMAL ENERGY STORAGE WITH LARGE CAPACITIES	ENERGY			DLR/BUHL
General advancement of knowledge	Integration strategies for thermochemical energy storages	NO		STORAGE INTEGRATION AND OPERATION	ENERGY			DLR/SIEMENS

In addition to the table, please provide a text to explain the exploitable foreground, in particular:

- Its purpose
- How the foreground might be exploited, when and by whom
- IPR exploitable measures taken or intended
- Further research necessary, if any
- Potential/expected impact (quantify where possible)

4.3 Report on societal implications

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	282889
Title of Project:	Thermochemical Energy Storage for Concentrated Solar Power
Name and Title of Coordinator:	Dr.-Ing. Marc Linder

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***0Yes 0No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***No***
RESEARCH ON HUMANS	
• Did the project involve children?	No
• Did the project involve patients?	No
• Did the project involve persons not able to give consent?	No
• Did the project involve adult healthy volunteers?	No
• Did the project involve Human genetic material?	No
• Did the project involve Human biological samples?	No
• Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	No
• Did the project involve Human Foetal Tissue / Cells?	No
• Did the project involve Human Embryonic Stem Cells (hESCs)?	No
• Did the project on human Embryonic Stem Cells involve cells in culture?	No
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	No
• Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	No
• Were those animals transgenic small laboratory animals?	No
• Were those animals transgenic farm animals?	No
• Were those animals cloned farm animals?	No
• Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	No
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	No
DUAL USE	
• Research having direct military use	0 Yes 1 No

• Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		1
Work package leaders		6
Experienced researchers (i.e. PhD holders)	1	6
PhD Students	5	4
Other		4

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**4**
Of which, indicate the number of men:	

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

○ Yes
⦿ No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective → Very effective
❑ Design and implement an equal opportunity policy	○ ○ ○ ○ ○
❑ Set targets to achieve a gender balance in the workforce	○ ○ ○ ○ ○
❑ Organise conferences and workshops on gender	○ ○ ○ ○ ○
❑ Actions to improve work-life balance	○ ○ ○ ○ ○

○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

⦿ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

⦿ Yes- please specify Study theses (Bach/Mas

○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

⦿ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

○ Main discipline[10]: Process and Energy Engineering / Industrial Chemistry
○ Associated discipline[10]:
○ Associated discipline[10]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

○ Yes
⦿ No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No
○ Yes- in determining what research should be performed
○ Yes - in implementing the research
○ Yes, in communicating /disseminating / using the results of the project

[10] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level? ○ Local / regional levels ○ National level ○ European level ○ International level	
H Use and dissemination	
14. How many Articles were published/accepted for publication in peer-reviewed journals?	**12**
To how many of these is open access[11] provided?	**3**
How many of these are published in open access journals?	**3**
How many of these are published in open repositories?	**0**
To how many of these is open access not provided?	**9**
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ☒ no funds available to publish in an open access journal ❑ lack of time and resources ☒ lack of information on open access ❑ other[12]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**2**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**

17. How many spin-off companies were created / are planned as a direct result of the project?	**0**
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑ Increase in employment, or	❑ In small & medium-sized enterprises
❑ Safeguard employment, or	❑ In large companies
❑ Decrease in employment,	❑ None of the above / not relevant to the project
☒ Difficult to estimate / not possible to quantify	

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:* *3*

[11] Open Access is defined as free of charge access for anyone via Internet.
[12] For instance: classification for security project.

Difficult to estimate / not possible to quantify	☒

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes ◉ No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes ◉ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

☐	Press Release	☒	Coverage in specialist press
☐	Media briefing	☒	Coverage in general (non-specialist) press
☐	TV coverage / report	☐	Coverage in national press
☐	Radio coverage / report	☐	Coverage in international press
☒	Brochures /posters / flyers	☒	Website for the general public / internet
☐	DVD /Film /Multimedia	☒	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

☒	Language of the coordinator	☒	English
☒	Other language(s)		

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]