High Temperature $CaO/CaCO_3$-Storage for Flexible Steam Power Plants

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Why carbonate storage?

Thermochemical high temperature heat storage allows **highest** gravimetric and volumetric **storage densities**. The system around the reversible reaction CaO + CO2 ↔ $CaCO_3$ excels with 0.6 kWh/kg and 1340 kWh/m^3 at 890 °C equilibrium temperature [1] and surpasses sensible and latent heat storage systems by far. The high discharge (carbonation) temperature level at 650 to 850 °C allows for **high pressure steam generation** and therefore shows potential to generate **zero emission power** from stored renewable surplus energy in connection with existing power plant infrastructure.

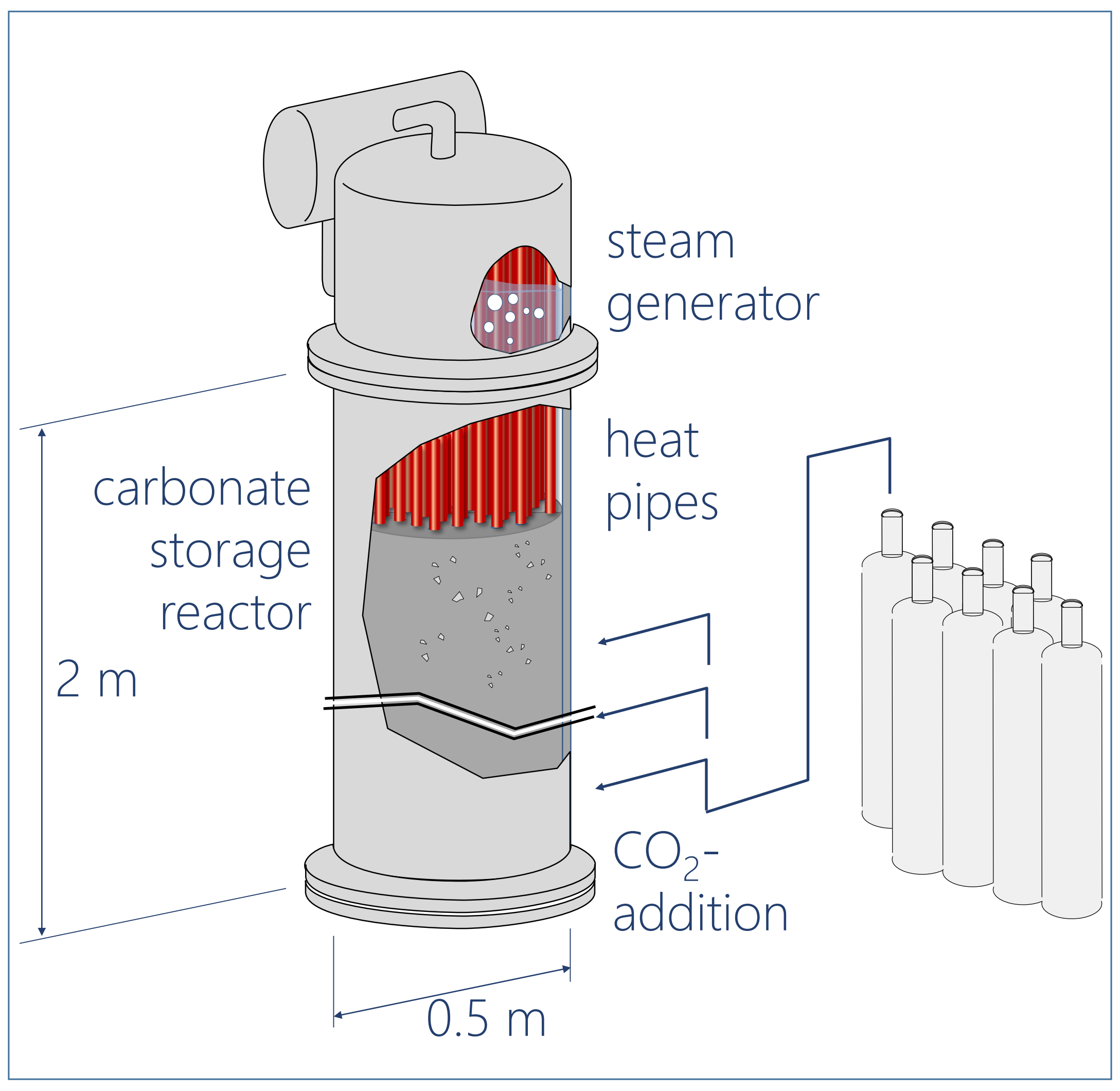


Figure 1: setup of pilot high temperature carbonate storage

Goals

Project goal is the **development, technical demonstration, and characterisation of a carbonate storage reactor with high heat flux densities**. As part of the characterisation we analyse cyclical CaO conversion in fluidised bed operation compared to own and literature TGA experiments.

Furthermore, we analyse potential **application scenarios** thermodynamically via a simulated storage integration in existing steam power plants at different pressure and temperature levels.

Table 1: parameters of lab- and pilot-scale reactor

	Lab-scale	Pilot-scale
Dimensions	Ø 158 mm, H: 1200 mm, 1 HP	Ø 498 mm, H: 2000 mm, 12 HPs
Storage capacity	6 kWh heat of carbonation	90 kWh heat of carbonation
Discharge power	2 kW steam ≈ 3,5 kW reaction	30 kW steam ≈ 35 kW reaction
Solids inventory $CaCO_3$	20 kg, d_p = 0,09 – 0,315 mm	300 kg, d_p = 0,09 – 0,315 mm
Fluidisation media	Up to 3 m^3_N/h N_2/CO_2/air, steam	Up to 30 m^3_N/h CO_2/N_2/air, steam

Challenge & Innovation

State of the art sensible high temperature storage conventionally uses gas heat transfer. The achievable fixed bed gas heat transfer coefficients below 100 W/m^2K [2] are sufficient for these applications. However, to allow the use of high power density carbonate storage, a new heat transfer concept with considerably higher heat flux density is necessary.

With heat transfer coefficients of 500 to 1500 W/m^2K high temperature sodium heat pipes possess **ideal heat transfer capacities in fluidised bed systems** [2]. Through their isothermal temperature profile they enable a considerably larger reaction zone than in fixed beds. This leads to a higher heat flux which heat pipes can easily transfer. This innovative concept thus allows the efficient use of high power density $CaCO_3$/CaO-storage to support steam power plants.

Concept

Surplus electricity is used to drive the calcination reaction and charge the storage via heat pipes. We use heat pipes for both, heat transfer in and out of the reactor. During discharge (carbonation) the fluidised bed transfers heat to the heat pipe which in turn fires the steam generator on top of the reactor (figure 1)

Process parameters for calcination of $CaCO_3$ are between 800 and 950 °C and 0 to 1 bar_a CO_2 partial pressure. Steam can be used as an easily separable fluidisation medium and additionally positively influences cyclical CaO conversion [3]. Carbonation takes place under pure CO_2 atmosphere at 1 bar and up to 850 °C.

Methods

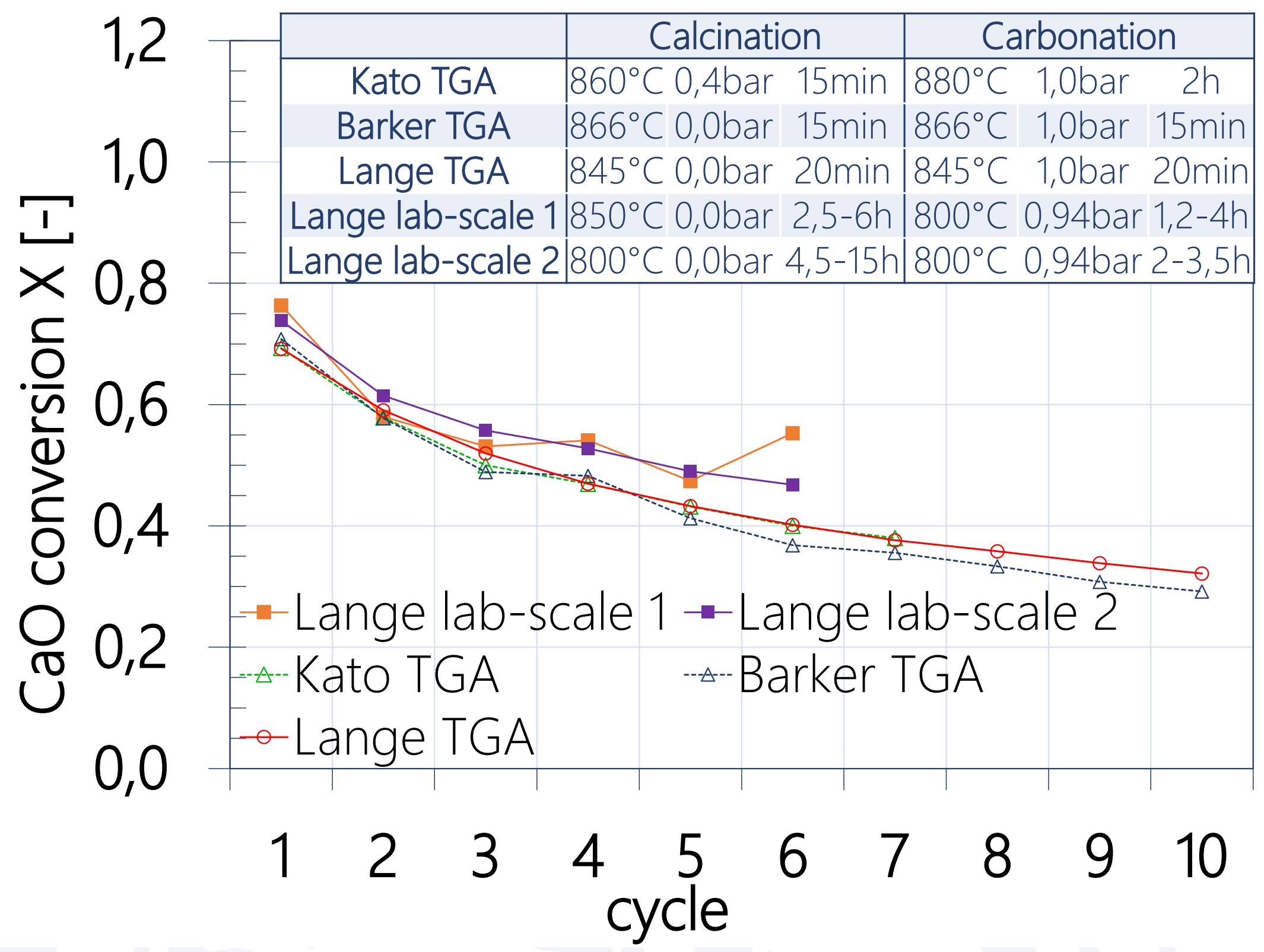
A lab-scale carbonate storage was established in 2019 whereas a pilot-scale with 12 heat pipes is currently under commissioning. (data in table 1)

The **lab-scale** unit enables us to achieve a high number of cycles to discern the influence of varying operating parameters, especially calcination and carbonation temperature, CO2 partial pressure and fluidisation conditions.

The **pilot-scale** unit offers the possibility to record detailed temperature profiles around the heat pipes to assess heat transfer coefficients. Additionally we will be able to generate valid characterisation data for upscale to application size.

Results from Lab-Scale Storage

During cyclic lab-scale experiments we discovered a positive influence of stationary fluidised bed carbonation, probably because of longer contact time. CaO conversion after 6 cycles was close to 50 %. This exceeds literature and own TGA measurements (figure 3).



	Calcination			Carbonation		
Kato TGA	860°C	0,4bar	15min	880°C	1,0bar	2h
Barker TGA	866°C	0,0bar	15min	866°C	1,0bar	15min
Lange TGA	845°C	0,0bar	20min	845°C	1,0bar	20min
Lange lab-scale 1	850°C	0,0bar	2,5-6h	800°C	0,94bar	1,2-4h
Lange lab-scale 2	800°C	0,0bar	4,5-15h	800°C	0,94bar	2-3,5h

Figure 2: CaO conversion of lab-scale reactor compared to own and literature TGA experiments

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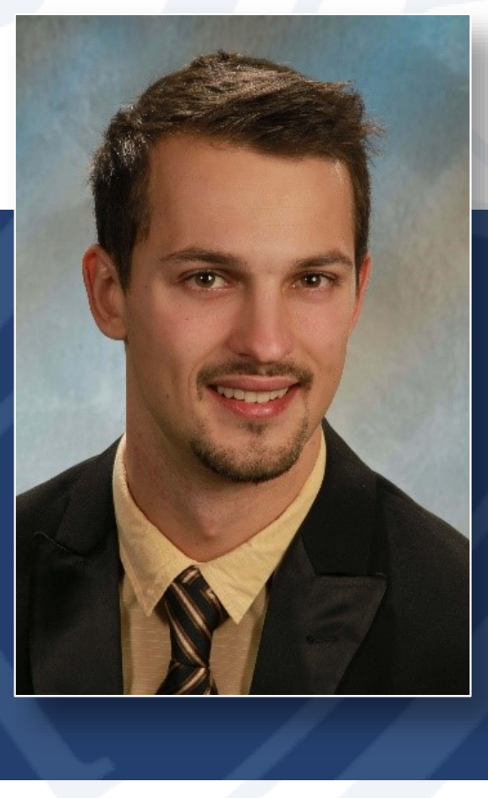

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