Exploring Underground CO_2 Energy Storage for Innovative Electro-Thermal Applications: An analysis for Deep Saline Aquifers

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The CEEGS Project

CEEGS, a Horizon Europe-funded initiative, aims to pioneer a cross-sectoral technology that integrates renewable energy storage using the transcritical CO2 cycle, geological CO2 storage, and possibly a minor geothermal heat extraction. The project aims to overcome the complexities of the interface between surface and underground components and bring the technology from TRL 2 to TRL 4.

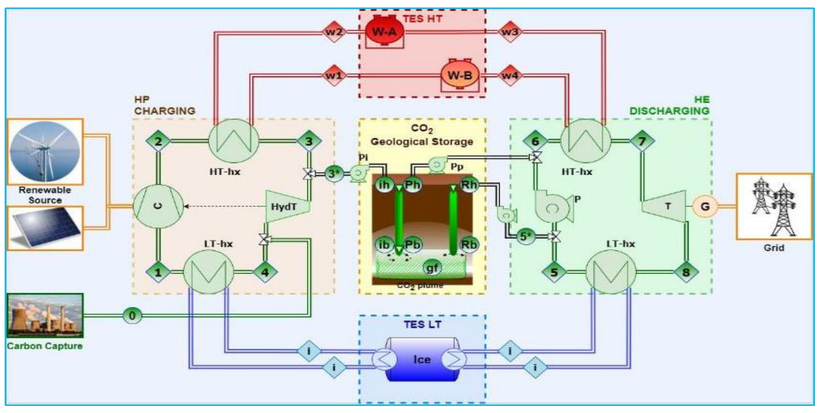


Figure. 1. Conceptual scheme of the CEEGS system incorporating electrothermal energy storage and CO2 geological storage into salt cavities

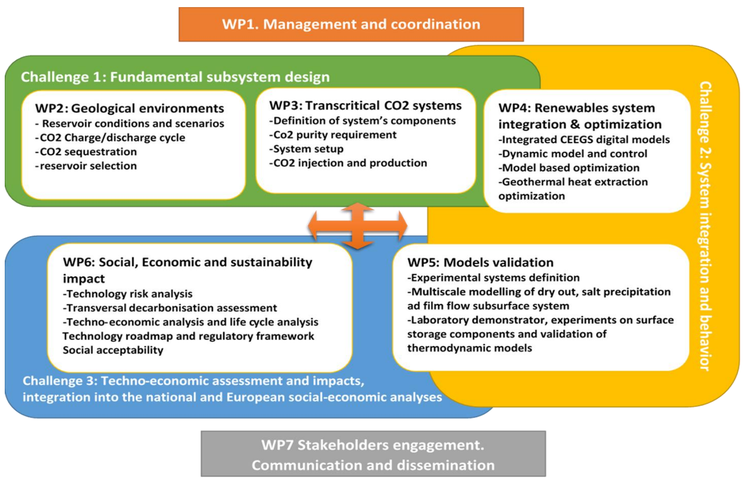
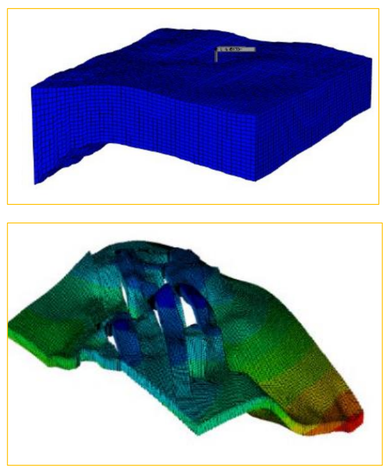
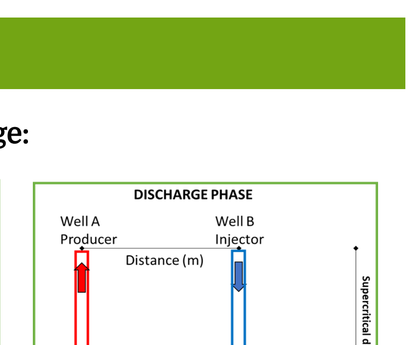


Figure. 2. CEEGS methodology structure

WP2 Geological Environment

Objectives:
1) Establishing realistic geological scenarios.
2) Investigating reservoir behavior under cyclic storage conditions.
3) Developing screening and ranking criteria for the selection of reservoirs.





Geological Environement

Porous media | Salt caverns

Open DSA | Closed DSA | Depleted Hydrocarbon field | Geothermal reservoir | One Salt Cavity | Multiple Salt Cavities

Results

1. Balancing CO2 Cycles for Effective Geological Storage:

The injection and back production of CO2 consist of a doublet, Well A and Well B. While the doublet is feasible, the implementation of the CEEGS concept may necessitate multiple injection and back production wells. In a doublet setup, during the charging phase, well A injects CO2 at a constant rate to store it in the supercritical phase.

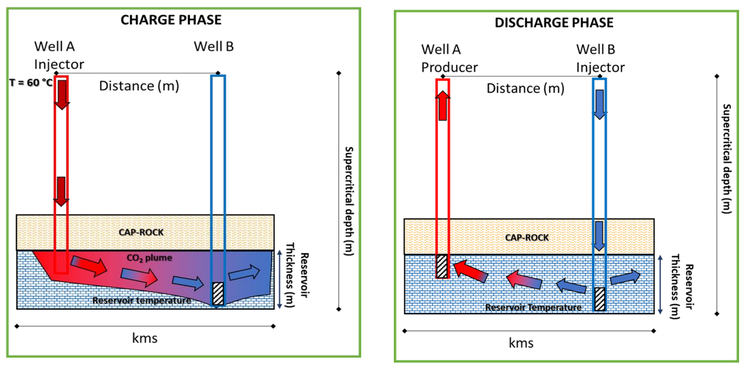


Figure. 3. Schematic diagram of the charge (a) /discharge (b) cycle in an open structure in a porous media reservoir

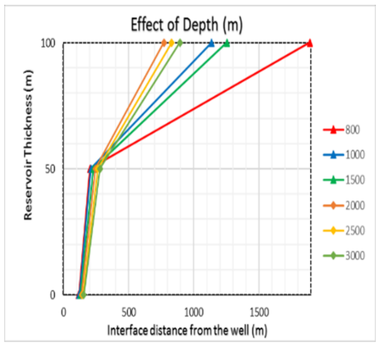


Figure. 4. CO2 / brine interface location as function of porous media reservoir depth, for constant Mw = 100 kg/s, injection for 100 days, Brine density 1025 kg/m3, well diameter 50 cm (Obtained by analytical model of Nordbotten and Celia (2006) model

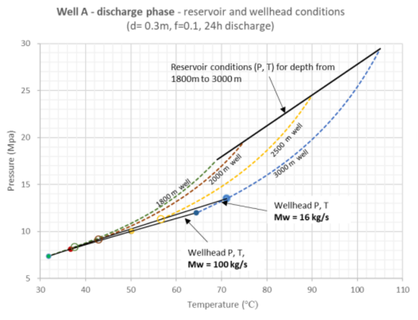


Figure. 5. Pressure and temperature profiles in well A during the discharge phase, as it back-produces CO2, at mass rates of 16 kg/s (0.5 Mt/year) and 100 kg/s (3.1 Mt/year). Empty circles represent P-T conditions at the wellhead for a mass flow rate of 16 kg/s, while filled circles represent P-T conditions at the wellhead for a mass flow rate of 100 kg/s. (Obtained by semi-analytical model by Adams et al. 2014)

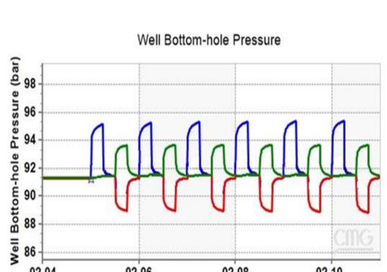


Figure 6: Bottomhole pressure variation in wells A and B during six charge and discharge cycles. X-axis is time in month-day.

2. Assessment of the impact of geological conditions on the efficiency of the system:

Numerical and semi-analytical simulations analyze transient P-T behaviors in boreholes and reservoirs during charge/discharge cycles, impacting system efficiency. CMG software models porous deep saline aquifer scenarios (wellbores and reservoirs), assessing CEEGS feasibility through well indexes and gross efficiency.

Property	Base Case	+1000m	+2000m
Injection Flow rate (kg/s) (Well A&B)	33	33	33
Well A			
Injection Pressure (bar)	75	105	130
Injection Temperature (°C)	60	60	60
BHP (bar) (charge phase)	95	193.6	297.1
BHP (bar) (discharge phase)	88	187.4	291.3
Injectivity (Kg/day/bar^2)	3674	2521	1518
Surface conduction of Well A during production			
Gas rate (kg/min)	1954	1954	1954
Water rate (kg/min)	56	0.83	0.8
Pressure (Bar)	67	86.4	113.1
Temperature (°C)	36.6	41.8	47.3
Productivity (Kg/day/bar^2)	6374	2382	1800
CO_2 State	Gas	Supercritical	Supercritical
Well B			
Injection Temperature (°C)	20	20	20
Injection pressure (bar)	75	80	95
BHP (bar)	93	193.3	296.4
Injectivity (Kg/day/bar^2)	6475	2640	1909
Sustainability	0.79	1.08	0.95
Gross Efficiency (%)	69.3	104.4	151.5

Table 1. presents a summary of key parameters for the three reservoir depth variants. As the depth of the reservoir increases, the water production rate decreases which is advantageous for surface facilities. Secondly, the production at such depths occurs in the supercritical phase, aligning with the requirements of the CEEGS technology. Moreover, there is a significant increase of gross efficiency with reservoir depth, due to the growing contribution of geothermal heat gain to the temperature of the CO2 in the production phase.

3. CO2 sequestration potential and impact

We explore CO2 sequestration with a focus on understanding the CO2 trapping mechanisms within transcritical cycles. Realistic geological scenarios, such as open-boundaries deep saline aquifers, are examined via simulations using CMG-GEM. The chemical equilibrium conditions in the reservoirs and the main chemical reaction were identified using PHREEC while GEM was used to identify the main sequestration mechanisms. This approach enables us to discern CO2 sequestration mechanisms during the plume setup phase and assess the impact of charge-discharge cycles on the chemical composition of the CO2 stream.

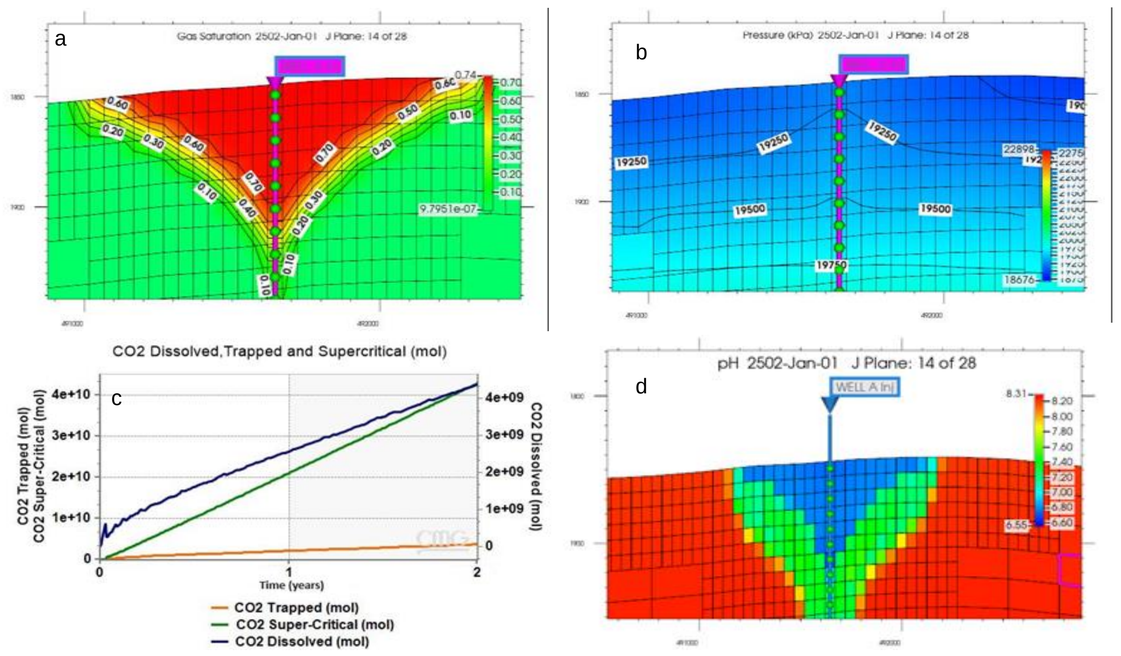


Figure 7. a) Spatial distribution of CO2 saturation, b) pressure (bar) around injection well (well A), after 2 years of continuous injection. c) Amount of CO2 dissolved, supercritical CO2, and in residual during plume setup stage. d) pH in the formation fluid after plume setup stage.

4. Screening and ranking methodology for selection of reservoirs

Identifying ideal locations for deploying CEEGS technology involves delineating key geological attributes to screen and prioritize potential sites. Various geological media and settings have been evaluated and ranked based on prior studies.

TYPE OF RESERVOIR	Deep saline aquifer	Criteria	Data
Mandatory criteria (CO2 storage safe according to technology and legal requirements)	Storage site definition	DEPTH of storage formation	>1300m
		SEAL thickness	>50m
		BRINE salinity	>10000 ppm TSD
	Storage site Lithology	% CLAY (mass)	<30%
	Petrophysical properties	Absolute Porosity (intergranular)	<15%
		Seal permeability	<0,02 mD
	Risks (complex area) (indentified or expected)	Open Faults	NO
		Active faults	NO
		Abandoned wells	NO
	Storage site		
Priorization criteria Focus on priorities: (1) Q recovery; (2) Q storage (3)CO2 storage	Storage site definition	Structure closure	Closed
		Thickness	10-100m
		Brine salinity	>100000 ppm TDS
	Lithology	Homogeneity and lateral continuity	Homogeneous
	Petrophysical properties	Permeability	10-1000 mD
		Absolute Porosity	10-15%
	Geomechanical properties	Fractures networks	Null/low
	Thermal properties	Heat Flow Density	>70mW/m2
		Rock thermal capacity (J/Kg.K)	>800 J/(kg.K)
	Complex Area Features	Natural seismicity	Low/null

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