Numerical Assessment of Subsurface Dynamics During Operation of the Innovative CO_2-based Electrothermal Energy and Geological Storage System (CEEGS)

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Introduction

CEEGS is a cross-sectoral technology that integrates renewable energy storage using the transcritical CO_2 cycle, geological CO_2 storage, and even geothermal heat extraction. The system offers flexibility in several aspects to enable buffer capacity to balance energy surplus and demand

- Temporal function
  - Short-term (hours to weeks) and long term (seasonal) storage
- Operational function
  - Open mode (external carbon source available) and closed mode.

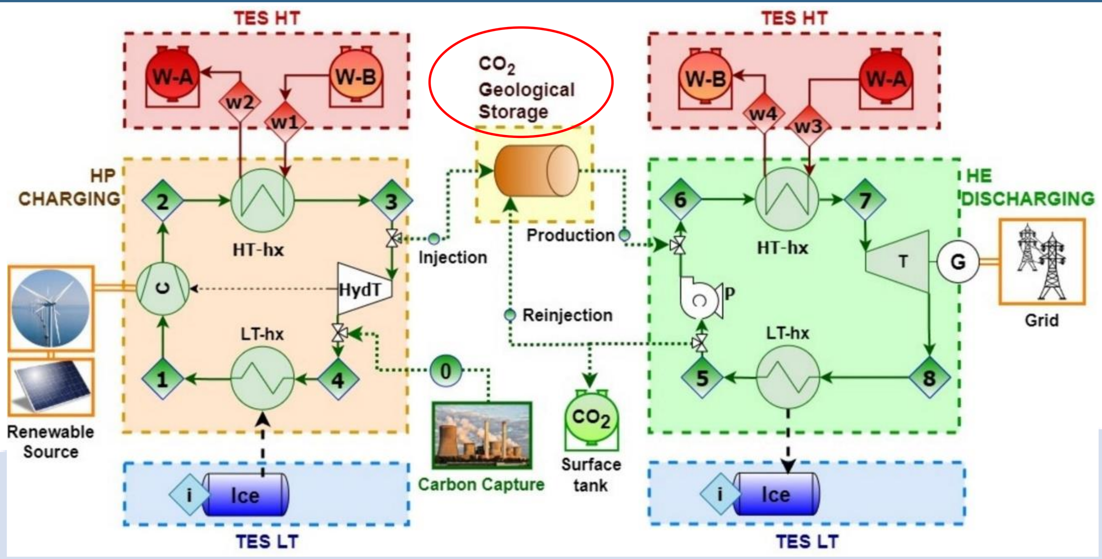


Fig. 1 Conceptual scheme of the CEEGS system incorporating electrothermal energy storage and CO_2 geological storage [1].

The project aims to overcome three main challenges in order to bring the technology from TRL 2 to TRL 4. These include the integration of surface and surface components, the design of novel components for the operation with supercritical CO_2 as working fluid and the evaluation of techno-economic feasibility as well as social and environmental impacts.

Challenge 1: Integration of surface and subsurface components

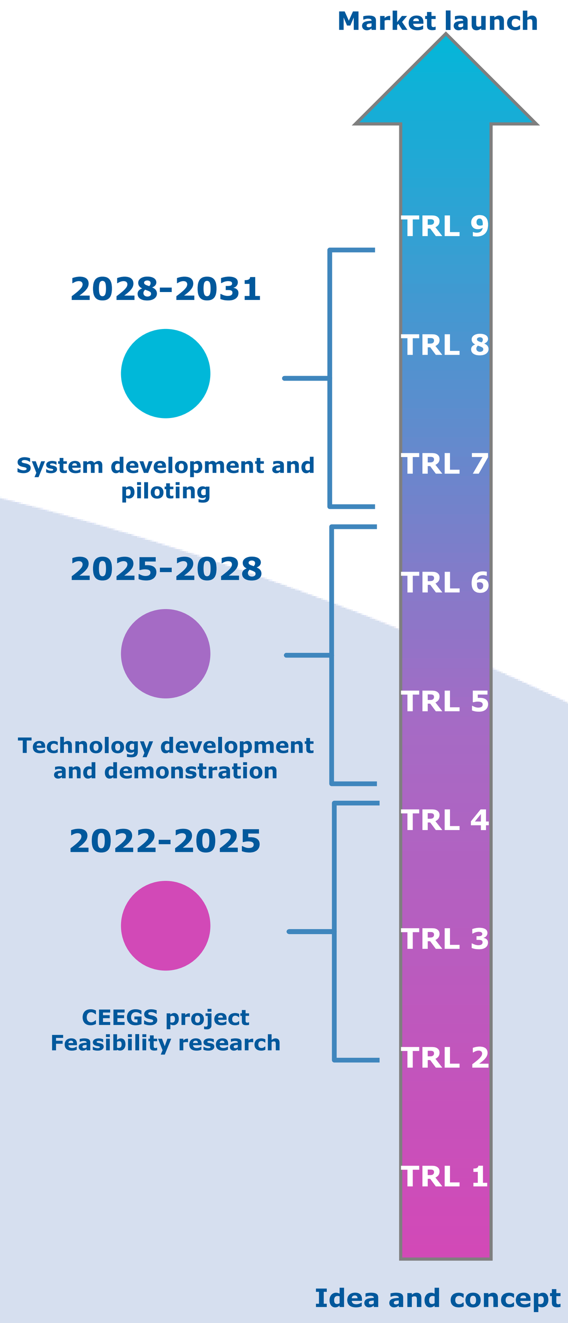
- Understanding the processes and components under the conditions required for an integrated geological storage system.
- Understanding the impact of realistic geological scenarios and conditions that represent major application cases across Europe.

Challenge 2: Conceptual design of novel components

- Designing the engineering components of the system: gas cleaning system, power and pumping elements, wells designs, operation and control.
- Defining the operation modes, and integration of solar and wind facilities with the existing energy system infrastructure.

Challenge 3: Techno-economic feasibility and impacts

- Conducting Life Cycle Analysis and identification of business model, markets and socio-economic risks and impact
- Assessment of social acceptance and making proposals for public engagement.



Method

Numerical Simulation Tool CMG-GEM

- Industry-standard reservoir simulation software [2]
- Multiphase multicomponent flows in porous media
- Peng-Robinson EoS [3]
- 2 components: CO_2 and H_20

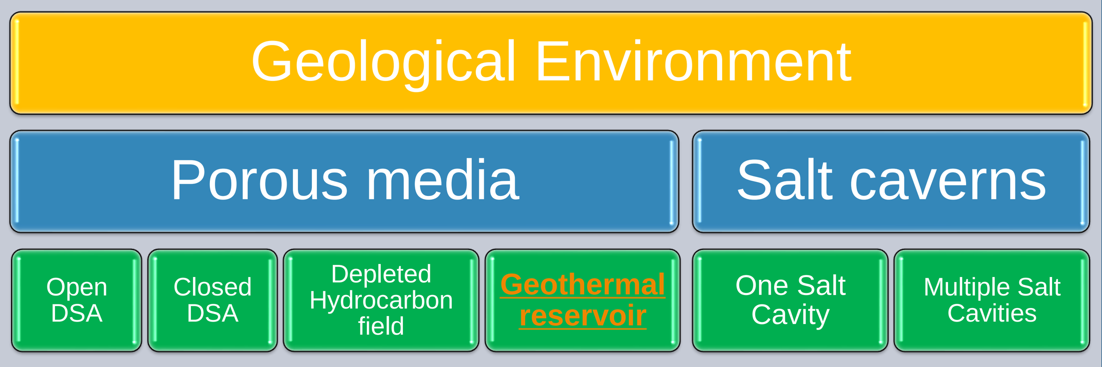


Fig. 2 Geological scenarios investigated for the feasibility of CEEGS plant.

Implementation steps

Step 1
- Numerical implementation of the scenarios and modelling the charging and discharging cycles using dynamic reservoir simulators

Step 2
- Numerical simulation of CO2 flow in reservoir and the wells
- Determination of injectivity and productivity of the wells

Step 3
- Study the effect of reservoir heterogeneity and stream impurities on the CO_2 plume behaviour
- Sensitivity analysis of injectivity and productivity to reservoir parameters

Model setup

A hypothetical geothermal reservoir is tested at several km depth with a doublet.
Prior to energy storage phase CO_2 is injected in a well store it in the supercritical phase. The injected CO_2 migrates upwards and away from the well towards another well due to high temperature in the geological reservoir.
During the energy storage phase, first discharging phase, hot CO_2 at a constant rate is back-produced from another well, while the used and cooled CO_2 is reinjected in the injector. In the charge phase, CO_2 is injected in the injector.

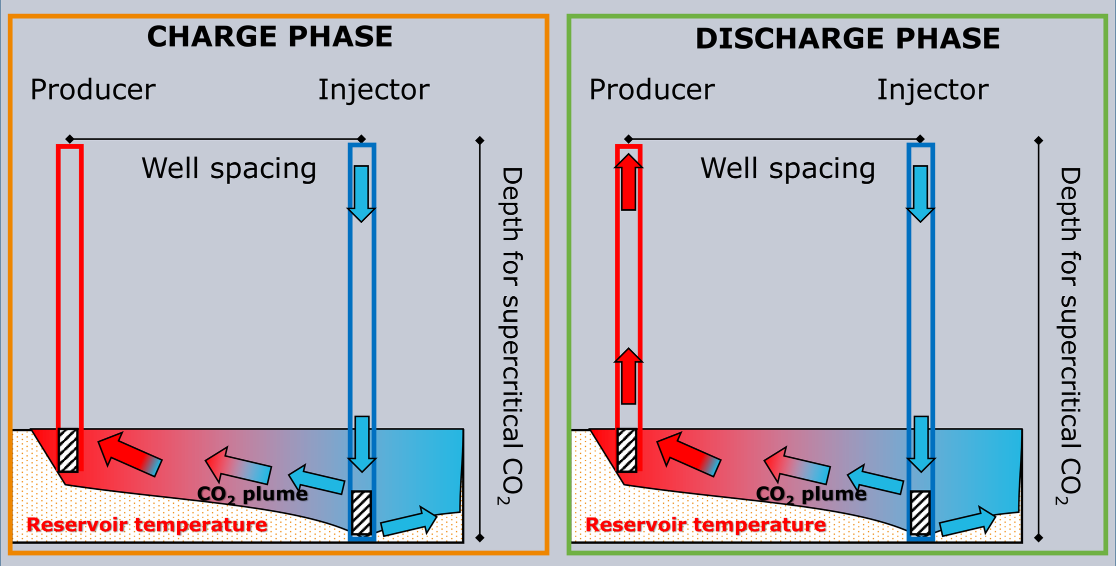


Fig. 3 The injection and back production of CO_2 is realised in a doublet.

Results

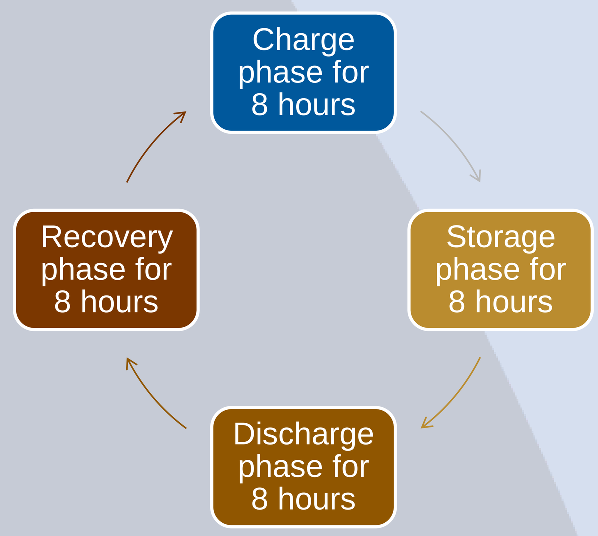


Fig. 4 Hypothetical cycle scheme for short-term energy storage.

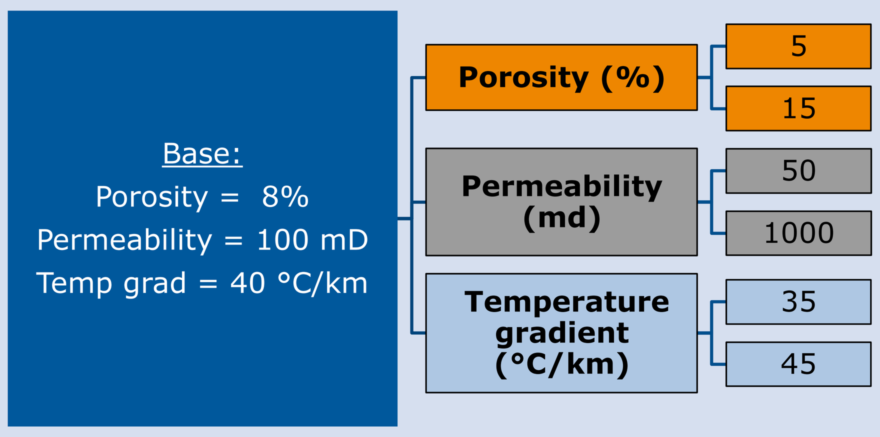


Fig. 5 Overview of input parameter for sensitivity study in a given reservoir.

Table 1 Molar composition of generic injection gas streams based on [4].

Component (mol %)	Pure CO_2	Stream A	Stream B
CO_2	100	96	92
N_2	-	0.2	1
O_2	-	2.1	6.5
Ar	-	1.7	0.5

Plume setup phase

The investigation of well spacing for the plume setup at a given flow rate and duration aims at finding the optimal well spacing, i.e. critical and maximum distance from injector where gas saturation is 0.4 along the complete perforation interval in order to minimise water saturation in the producer.

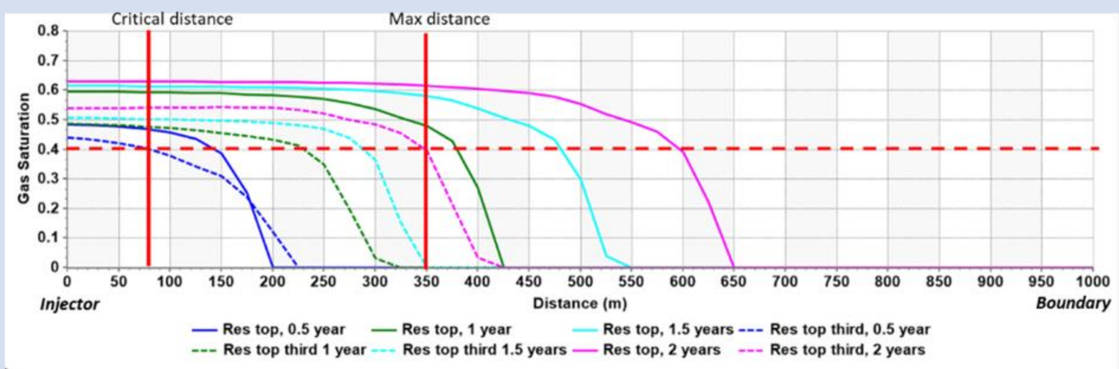


Fig. 6 Gas saturation profiles in the geothermal reservoir around the injector well towards model boundaries at two depths representing perforation top and bottom for the producer (solid – reservoir top, dashed – bottomhole) for various plume setup durations. The dashed line represents the desired minimum gas saturation at producer bottomhole.

Energy storage phase

During the energy storage phase, the goal is to achieve repetable energy storage cycles at desired mass flow rates within operational limits, i.e. flowing bottom-hole pressure can deviate maximum by 20% of the static pressure during injection and production. Furthermore, the water production rate should be as minimal as possible.
The simulation results show that impurities have minor effect on the efficiency of the energy storage cycles.

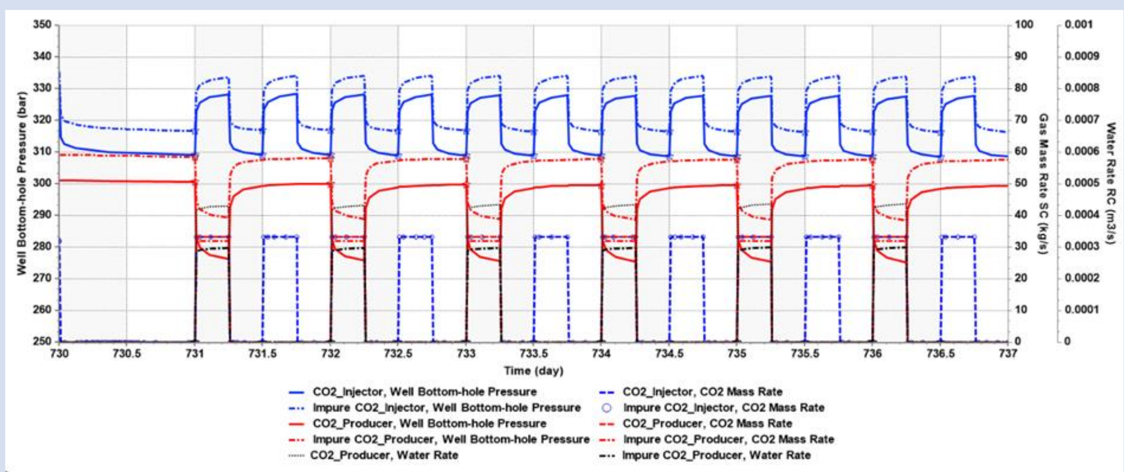


Fig. 7 Simulated wellbore pressures, temperatures and mass rates during the charge and discharge cycles in the base case geothermal reservoir with pure CO_2 and the effect of stream impurity on system performance. Note that both injection and production mass rates are positive.

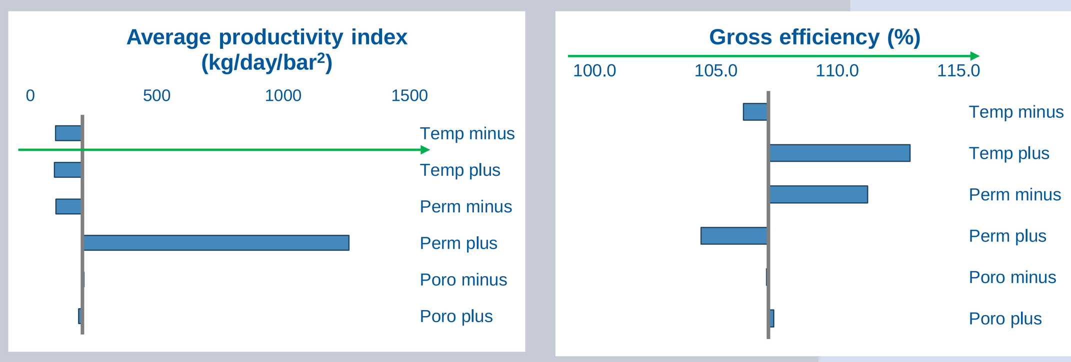


Fig. 8 Tornado diagrams illustrating the sensitivity of geological parameters on average productivity index and gross efficiency in the geothermal scenario. The analysed geological parameters are temperature (temp), permeability (perm) and porosity.

The sensitivity study of the geological parameters of the geothermal reservoir study reveal that productivity is mainly controlled by permeability. However, larger permeability negatively effects gross efficiency due to increased reservoir pressure loss.

Discussion and conclusions

- The generic geothermal reservoir with realistic geological parameters and operational parameters can provide promising well productivity and gross efficiencies.
- Reservoir heterogeneity, especially permeability (transmissivity) can be a major concern. This will be studied in a separate project work package.
- Studied stream impurities slightly affect the well performance.
- Future work will investigate
  - working fluid loss due to trapping mechanisms; and
  - effect of CO_2-rock-brine interaction on long-term performance of the system, including potential change in composition of back-produced CO_2 stream.

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