CEEGS Cycle - Relevant System Characterisation (D3.5)

Deliverable D3.5 defines the main parameters and components integration within the base designs of the CEEGS project system. Two power scales, 5 MW and 100 MW, are considered for the analyses and designs to identify potential differences between applications, involved processes and components. It presents the results of the second part of Task 3.1, executed in the second year of the project. These results provide the framework for the specific design of components in Task 3.2, and they are used in subsequent tasks within WP3 and WP4. Processes and components are modelled and simulated, providing analyses oriented to different applications/solutions about the concept feasibility. Models for optimised parameters values, components integration and preliminary surface component-geological loop have been developed in Python code. These results provide the framework for the design of components and operation modes.
The cycle and component designs confirm the good performance of the system and raise different possibilities to address identified challenges, such as system balancing, alternative configurations, power equipment and heat exchangers. The developed component pre-designs and component analysis show that they can be addressed within the conditions of the cycles, with good performance in heat exchange, turbomachinery and thermal storage. They are suitable for different conditions and variable operation. The study demonstrates the feasibility of the CEEGS system for more advanced developments at higher TRLs and detailed engineering.

The main sections of the deliverable include:

- The transcritical CO_2 cycles are defined as a reference case. Integrating the charging and discharging cycles determines the round-trip efficiency of the entire electrical-to-electrical conversion process. The result is a range of efficiency that depends on the shape of the transcritical cycles and their integration with HT-TES & LT-TES thermal storage.

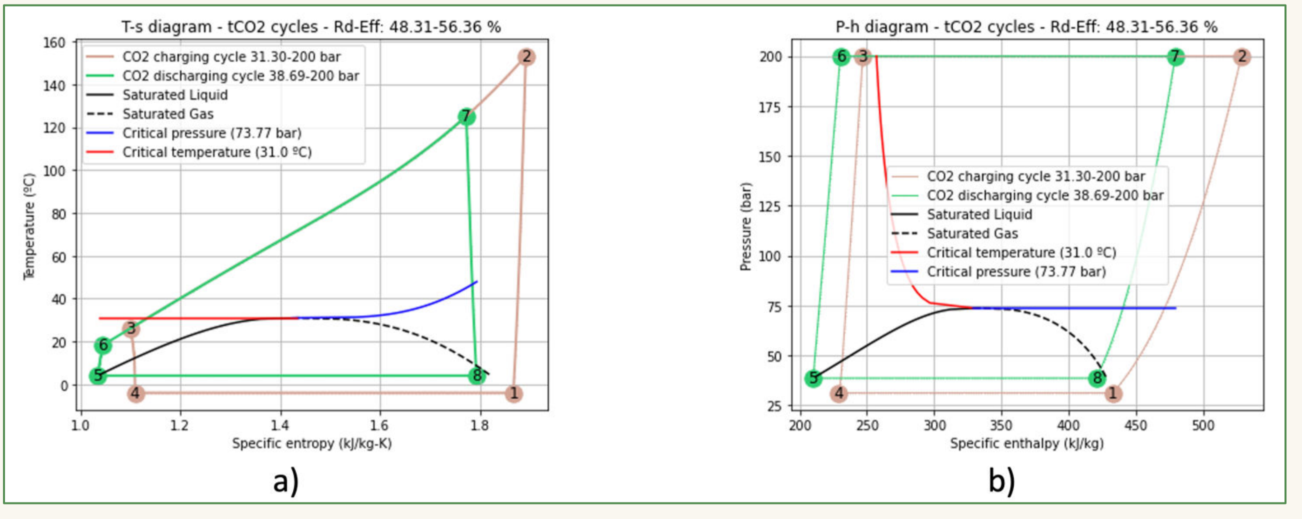

Figure 1. Diagrams of CO_2 transcritical cycles in the reference case: a) T-s, b) P-h.

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- The system balancing. System balancing has two options, regardless of which thermal energy storage reservoir is the 'limiting' or the 'excess' reservoir: the additional energy input into the 'limiting' reservoir and using the 'excess' energy in other applications. The different system balancing options successfully bring the round-trip efficiency of the CEEGS system under reference case conditions to a mid-range value in the range of 48.31-56.36%. Any of the options is feasible as a means of balancing the CEEGS system. The option selected will be conditioned by other factors, such as economic factors, depending on the cost of the additional equipment required.
- Alternative configurations. The approach of multi-stage compression with intermediate cooling and heat recovery in the intermediate reheat of multi-stage expansion has been successfully demonstrated. The use of staged compression can have associated advantages. Still, the coupling between the charging and discharging cycles reduces the enthalpy jump available in the turbine and increases the humidity at the turbine outlet. Incorporating the recovery of the cooling heat in an intermediate reheat in the discharging stage turbine increases the enthalpy jump of the turbine, and it reduces the humidity at the turbine outlet, obtaining efficiency values of around 46.1-54.5%, similar to those of the reference case.
- Evaluation of power equipment. Different feasible strategies for compressor integration and operation modes to obtain high performance of the systems under variable operation intrinsic to renewable sources.

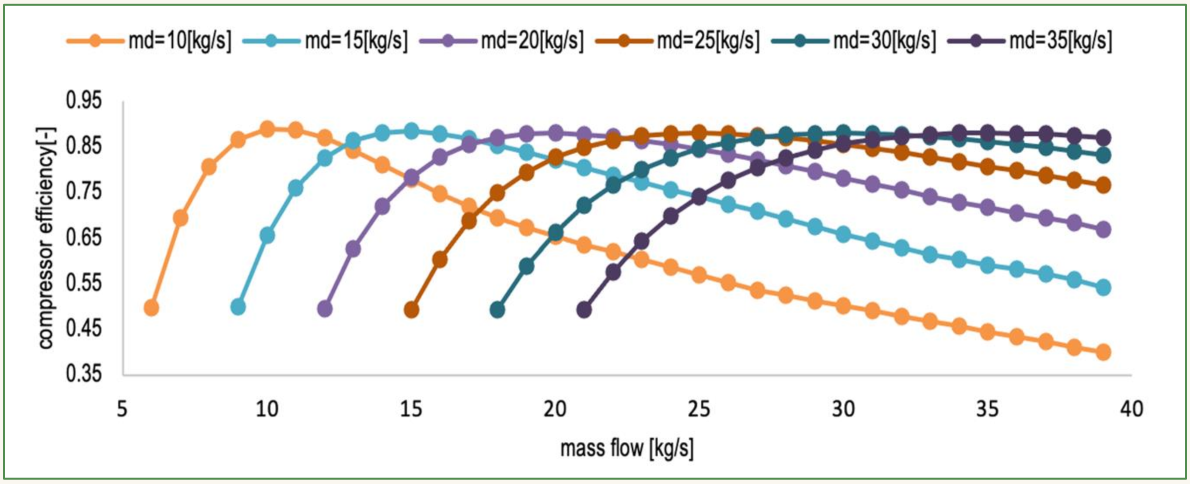

Figure 2. Internal compressor performance for compressors with different design flow rates relative to the flow rate flowing through the load cycle.

- Analysis of thermal storage. The multi-stage heat exchange allows the temperature profiles of the CO_2 and the storage fluid to be better adapted. Adjusting the heat transfer in each step allows the temperature profiles to be closer, maintaining the minimum temperature difference imposed in the assumptions at all times. The maximum temperature of HT-TES increases with the number of stages in the sensible heat transfer, along with the Turbine Inlet Temperature (TIT). The round-trip efficiency of the system also benefits from this. The LT-TES phase change temperature is critical to the system's cooling applications.

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Once the impact of the phase change temperature in LT-TES is considered, different integration possibilities with fluids that can provide the required conditions are also considered.

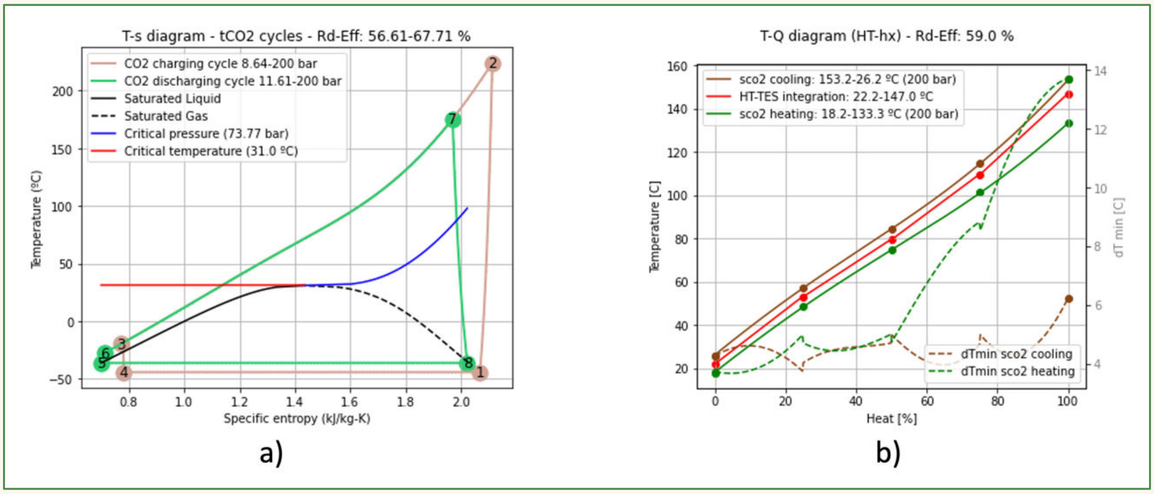

Figure 3. a) T-s diagram of the transcritical CO_2 cycles considering -40ºC in the phase change temperature in LT-TES, and Temperature-Heat (T-Q) diagram of the staged sensible heat transfer in the HT-TES.

- Heat exchanger design: The detailed shell & tube heat exchangers for the two power levels have been successfully developed in the EDR module of Aspen software. It includes design parameter sheets, thermal and constructional requirements and design drawings. Results show that technologically feasible designs can be integrated into CEEGS. In parallel, printed circuit heat exchangers (PCHE) are studied. They are interesting candidates for heat exchangers in the CEEGS concept, as they can potentially be more compact compared to conventional heat exchangers. In both cases, no limitations related to technology development were found.

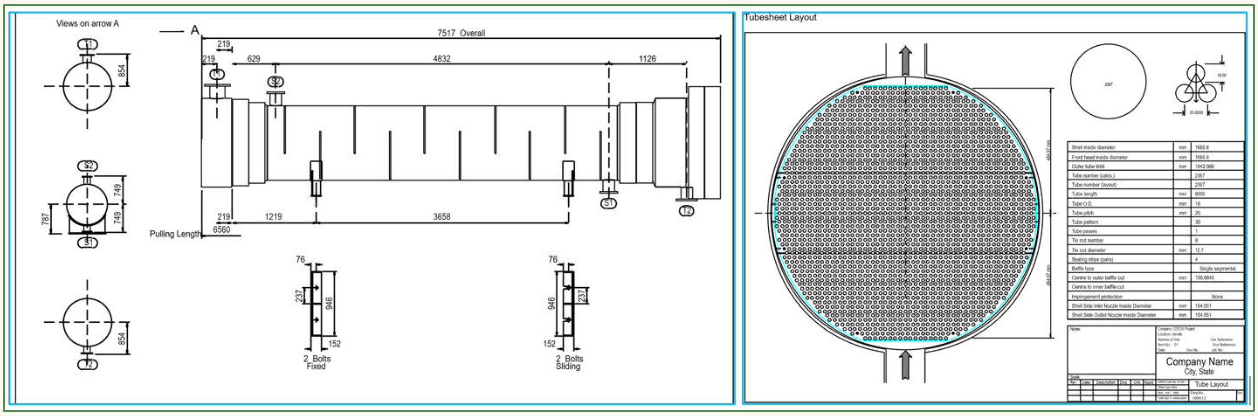

Figure 4. Tubesheet Layout. Shell and tube CO_2-Water heat exchanger on HT side – 5MW

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- The integration of surface cycles and subsurface processes. The CEEGS system expands its operational capabilities and applications, integrating geological production and injection processes that enable the storage of captured CO_2, maintaining its large-scale renewable energy storage, flexible power production and flexible coverage of heating and cooling demands. The range of round-trip efficiency increases to 51.04-60.68% at the referenced conditions. Geological production/injection processes have been successfully incorporated into the energy cycle. Energy storage occurs in mechanical and thermal forms. The system takes advantage of the geothermal gain of the ground.

The second period of task 3.1 has evolved satisfactorily, and relevant results regarding the layouts' definitions and parameters have been obtained. They allow advancing in the following steps within the related tasks in WP3 and WP4. The parameters and integrations defined have set the specifications for defining main components and subsystems (heat exchangers and turbomachinery, tanks, and others) performed in the second part of task 3.1. Their definition will interact with Task 3.2, cycle performance optimisation (charge/discharge cycle operation, circulating fluid volumes) and Task 3.4, CO_2 plume formation. Based on these specifications and analyses, the subsystems and components selected for integration in the different alternatives of the CEEGS cycle have been studied and optimised at the component level. The feasibility of cycles and components under the operation conditions has been demonstrated with different designs and solutions showing their potential for scalability. No limitations have been found in the development of the technology. The results support the feasibility of advancing the technology towards higher technological readiness levels.

How do I find out more about the project?

Video explainer: https://youtu.be/y94fHCM__us
Project Brochure: https://tinyurl.com/2p9hc9n4
Project Website: https://ceegsproject.eu/

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