



Centralized or Individual? Comparing CO₂ Conditioning Strategies for Industrial Clusters

Introduction

The development of carbon capture and storage (CCS) at industrial cluster scale requires multiple CO₂ sources to connect to transport and geological storage infrastructure. Captured CO₂ must often undergo conditioning to satisfy downstream pressure, phase and purity requirements. Depending on the characteristics of the captured stream, conditioning may involve compression, water removal, impurity removal and final pressurisation. It therefore forms an important link between the capture process and the wider transport and storage system.

Captured CO₂ streams are not uniform. Their composition and physical conditions depend on the industrial process, feedstock and capture technology. Streams from different emitters can contain different concentrations of impurities and may also be delivered at substantially different pressures. Previous studies have shown that these differences influence compression, dehydration, phase behaviour, purification and overall conditioning cost [1–4]. CO₂ concentration alone is therefore insufficient to characterise the conditioning requirement.

A further complication is that there is no single universal CO₂ specification for transport and storage. Existing projects impose different acceptance limits according to transport mode, operating conditions and downstream requirements. Specifications published for the Teesside, Porthos and Northern Lights, for example, differ in their requirements for CO₂ concentration, water and non-condensable components [5–7]. Conditioning requirements therefore depend both on the characteristics of the captured stream and on the receiving transport and storage system.

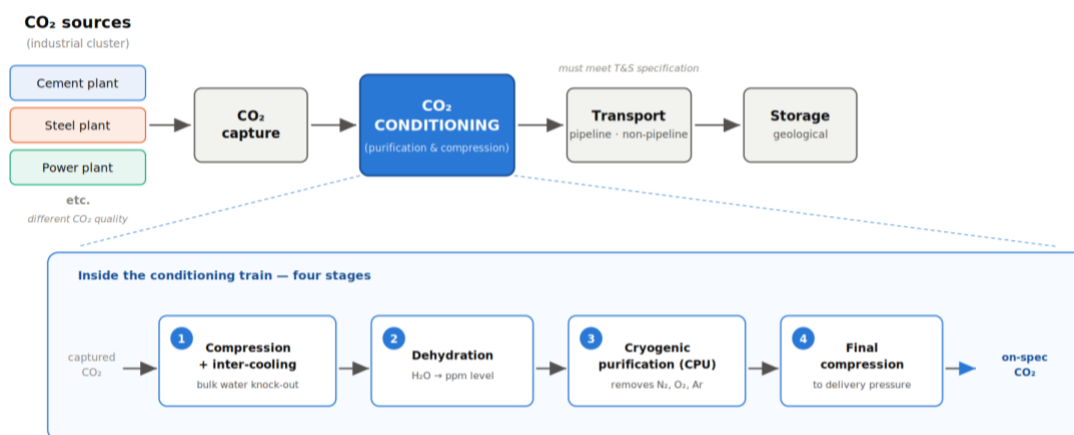


Figure 1. CO₂ conditioning within the CCS value chain and the four conditioning stages considered in this study.

Within an industrial cluster, each emitter could install and operate its own complete conditioning train. Alternatively, parts of the conditioning system could be shared between multiple emitters. The latter may reduce the number of installed units and provide economies of scale, but combining streams from different capture technologies introduces additional questions concerning feed quality, operating conditions, potential cost saving and the distribution of shared costs.

This work investigates individual and shared CO₂ conditioning for a set of heterogeneous industrial CO₂ streams. The objective is to assess how source characteristics influence conditioning requirements, compare individual and shared configurations on a common technical and economic basis, and establish a framework for examining when shared conditioning may be suitable within a wider industrial cluster system.



Method

Five predefined captured CO₂ scenarios are considered, representing a range of different stream profiles. The scenarios span a broad range of CO₂ concentrations, impurity contents and capture-outlet conditions. A common captured CO₂ flow rate of 12.5 tCO₂/h per emitter is adopted for the present base case so that the influence of stream quality and inlet conditions can be examined independently of differences in emitter scale.

The conditioning process is modelled in Aspen Plus and contains the four stages shown in Figure 1. The captured stream first undergoes multistage compression with intercooling and bulk water knock-out. This is followed by temperature-swing adsorption dehydration. The dry stream is subsequently treated in a cryogenic purification unit to remove non-condensable impurities before the purified CO₂ is pressurised to the required transport condition. A consistent thermodynamic and process modelling basis is applied to all scenarios.

Two conditioning configurations are evaluated, as illustrated in Figure 2. In Case I, each emitter operates an individual conditioning train. In Case II, initial compression remains located at each emitter because transporting the captured CO₂ at its low capture outlet pressure would be impractical and uneconomic. Each stream is therefore compressed individually to a common pressure before being transported and blended for shared dehydration and cryogenic purification.

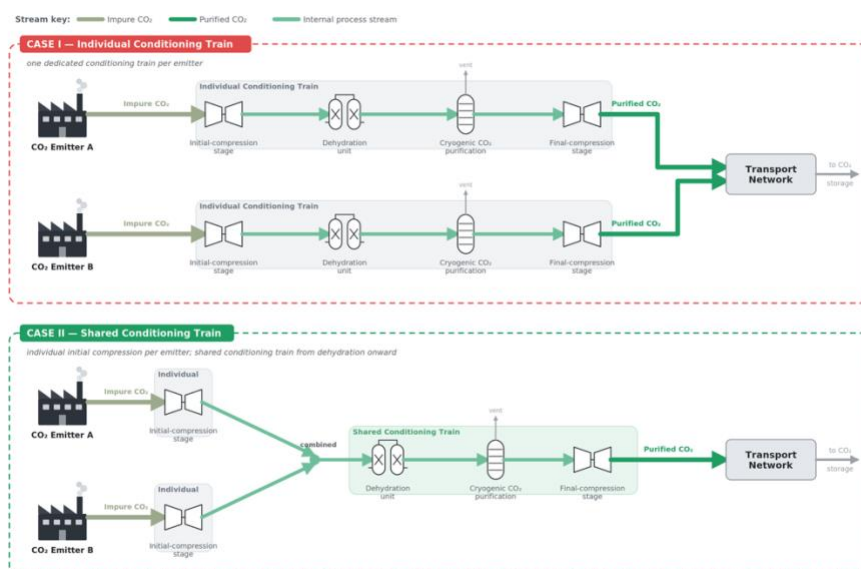


Figure 2. Individual and shared CO₂ conditioning configurations. In Case II, initial compression remains distributed while dehydration and cryogenic purification are shared.

The technical assessment considers power consumption, cooling duty, product quality and CO₂ recovery. The process model outputs are then transferred to a techno-economic assessment in which capital expenditure, operating expenditure and levelized conditioning cost are compared between the two configurations.

The purpose of the analysis is not only to compare two equipment layouts but also to distinguish the different mechanisms through which source characteristics affect conditioning. Capture outlet pressure primarily determines the front-end compression requirement, while the impurity profile influences the downstream separation requirement and the amount of CO₂ recovered as product.



Results and Discussion

The five individual scenarios show noticeable differences in conditioning performance because the captured streams have different feed conditions and impurity profiles. However, when the combined individual configuration (Case I) is compared with the shared configuration (Case II), the overall technical difference is relatively small.

This is mainly because initial compression dominates the overall energy demand and remains individual in both configurations. Only the downstream dehydration and cryogenic purification stages are shared in Case II, so the larger shared equipment provides only a modest whole-system energy benefit, while CO₂ recovery and final product quality remain broadly similar.

The more significant difference is economic. sharing several smaller dehydration and purification systems into one larger shared train reduces the number of installed units and allows economies of scale to be realised. The resulting capital cost reduction is therefore much larger than the corresponding reduction in energy demand. Operating cost savings are more moderate because electricity remains an important component of total annual cost.

These findings indicate that the main advantage of shared conditioning is associated with economies of scale, rather than with a fundamental change in the conditioning process itself. The shared configuration therefore becomes primarily an infrastructure and economic design question: whether the reduction in downstream equipment cost is sufficient to justify the shared arrangement within the wider cluster. When streams have different CO₂ qualities, the shared cost may not affect all emitters equally. Cost allocation is therefore important to ensure that the benefits of sharing are distributed fairly among participants.

Conclusion

The five individual scenarios show clear differences in conditioning performance because the captured streams enter the system with different pressures, compositions and impurity profiles. These differences affect the compression requirement, purification performance and CO₂ recovery, showing that the conditioning burden cannot be represented by CO₂ purity alone.

However, when the overall individual configuration is compared with the shared configuration, the technical difference is relatively small. This is mainly because the initial-compression stage, which represents the dominant part of the conditioning energy demand, remains individual in both configurations. The shared case therefore changes mainly the scale and number of downstream dehydration and cryogenic purification units rather than the overall process duty.

The economic comparison is more significant. Sharing the downstream conditioning stages reduces equipment duplication and allows larger units to benefit from economies of scale. The main economic advantage therefore comes from lower capital investment and, consequently, a lower levelized conditioning cost, while the reduction in operating cost is more moderate because energy consumption remains relatively similar between the two configurations.

Overall, the study indicates that shared conditioning can offer an economic advantage for industrial clusters even when the technical performance of the two configurations remains similar. The attractiveness of this approach will also depend on how the shared cost is distributed among emitters with different CO₂ qualities, making cost allocation an important part of the wider assessment.



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