# Advanced structured packing for economical decarbonisation

## Next-generation mass transfer technology unlocks efficiency gains in post-combustion carbon capture

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Decarbonising industrial sectors remains one of the foremost challenges in achieving global emissions reduction targets. As industries strive to meet increasingly stringent regulatory and sustainability objectives, solvent-based post-combustion carbon capture (PCCC) has emerged as the primary solution for mitigating $CO_2$ emissions from large stationary sources. Over several decades, the deployment of PCCC technologies has been instrumental in reducing the carbon footprint of sectors such as power generation, hydrogen production, cement, oil and gas, and waste processing, cementing its role as a cornerstone of industrial decarbonisation strategies.

Despite this maturity, PCCC faces two persistent and interrelated challenges: the evolution of solvent chemistries to improve $CO_2$ capture efficiency and reduce energy consumption, and the critical function of absorber and regenerator packing and internals in enabling these advancements. While significant attention has been directed toward solvent development, the design and performance of mass transfer packing and internals remain equally pivotal in determining the overall efficiency, operability, and cost-effectiveness of carbon capture systems.

A unique challenge in PCCC is its inherently low operating pressure, which makes blower energy the dominant operating cost. Flue gas can contain as little as 4% $CO_2$; consequently, this requires enormous volumes, often hundreds of thousands of cubic metres per hour, to be processed with minimal pressure drop, driving the need for absorber columns that can exceed 10-15 metres in diameter. Under these conditions, every millibar of pressure drop matters, so internals optimised for low-pressure operation provide significantly greater savings compared to conventional high-pressure designs, making advanced structured packing and efficient gas-liquid distribution critical for economic viability.

The scale of these towers presents unique engineering, construction, and operational challenges. Large-diameter columns require robust structural design to withstand internal pressures, wind loads, and seismic forces, while also ensuring optimal gas and liquid distribution across the entire cross-section to achieve the efficiency target. The height and volume drive up material, fabrication, and installation costs, making innovations that enable more compact and efficient design, such as advanced structured packing, even more valuable for the economic viability of large-scale carbon capture projects. Under these conditions, minimising pressure drop within the absorber is essential to reduce blower energy requirements and operational costs while maintaining high mass transfer efficiency to achieve stringent $CO_2$ removal targets.

Koch-Glitsch has developed Flexipac CP structured packing for aqueous amine systems in low-pressure PCCC applications. The design incorporates geometric enhancements that improve liquid spreading and maximise surface area utilisation, which are critical for efficient $CO_2$ absorption and mass transfer. These improvements deliver measurable benefits: higher $CO_2$ capture rates that reduce the overall cost of capture and reduced solvent requirements that lower emissions and regeneration energy costs. Optimised packing technology also enables smaller column dimensions, minimising capital investment for large-scale PCCC systems.

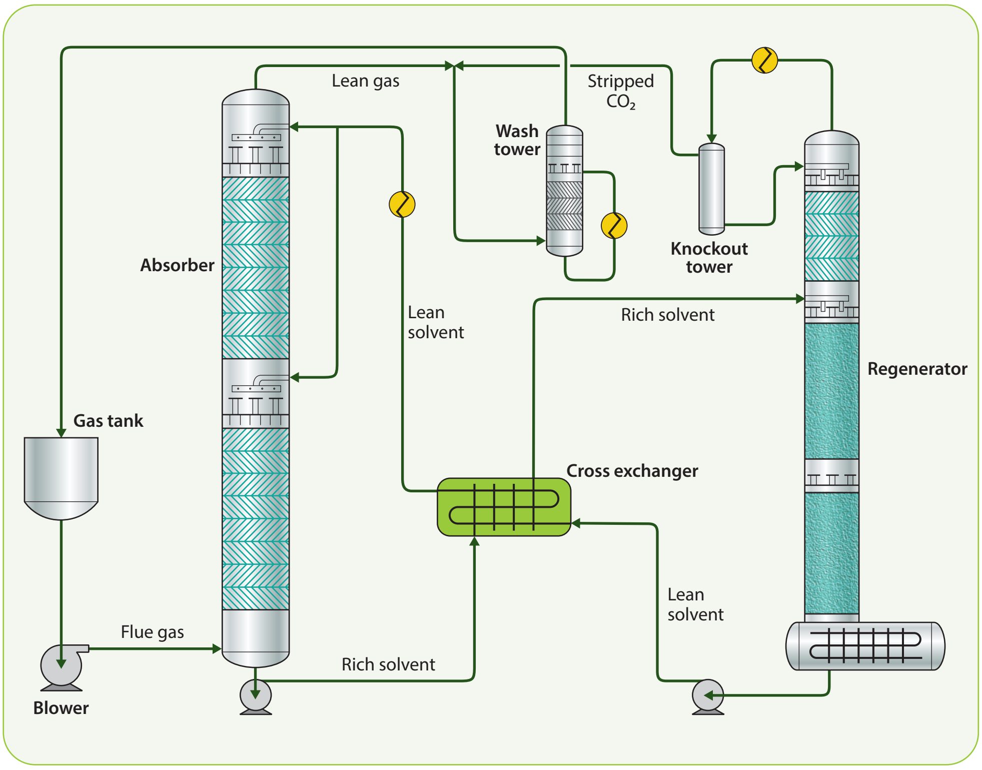


**Figure 1** Process flow diagram for Koch-Glitsch's PCCC test facility

degradation. On the liquid side, instruments include a total inorganic carbon analyser and Karl Fischer titration for water content measurement and control. Thermocouples throughout the column provide a detailed temperature profile, and temperatures are actively controlled to remain below thermal degradation limits. The pilot plant handles flue gas compositions simulating various point sources of $CO_2$, while the regenerator operates to maintain the desired solvent lean loading. Pilot testing can be configured to evaluate key PCCC variables, including absorber pressure drop, capture efficiency, regenerator specific reboiler duty, and operational limits such as foaming and flooding.

## Post-combustion carbon capture pilot plant

Koch-Glitsch operates a carbon capture pilot unit in Wichita, Kansas, using artificial flue gas to evaluate solvents and packing types, including conventional and Flexipac CP structured packings. The system includes an absorber, water wash, regenerator, and auxiliary equipment, as shown in **Figure 1**. It is equipped with advanced monitoring and control systems. On the gas side, $CO_2$ concentrations are measured at multiple absorber locations, and $O_2$ concentration is tracked with online gas analysers. Moisture content is monitored, and $O_2$ levels are kept low to minimise solvent

A series of amine-based solvents was evaluated at the carbon capture facility to verify the performance of various conventional and Flexipac CP structured packing. On average, Flexipac CP structured packing exhibits up to a 65% reduction in pressure drop, as illustrated in **Figure 2**. Additionally, it demonstrated up to a 25% increase in capture efficiency compared to the conventional structured packing (see **Figure 3**). As a result, it requires less height to achieve equivalent separation. The lower pressure drop

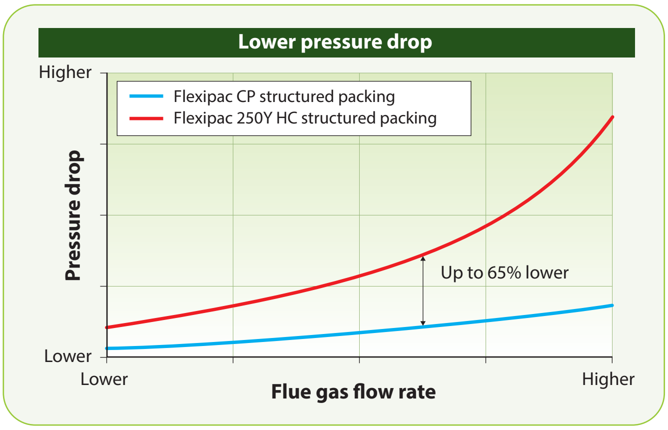


**Figure 2** Comparative performance of the pressure drop of Flexipac CP structured packing compared to Flexipac 250Y HC structured packing

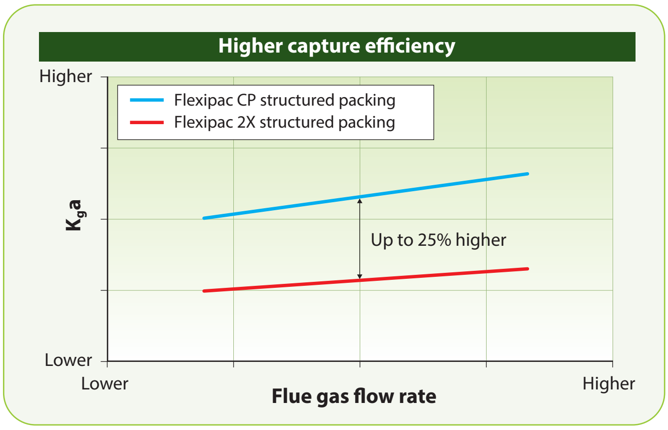


**Figure 3** Comparative performance of the efficiency of Flexipac CP structured packing compared to Flexipac 2X structured packing

contributes to energy savings and operational efficiency, while the reduced column height may enable more compact equipment design and decrease construction costs. These combined advantages position Flexipac CP packing as a solution for applications where spatial limitations and operating costs are pivotal factors.

Through extensive pilot-scale operation, the test facility has demonstrated the scalability and robustness of Flexipac CP structured packing under a range of simulated industrial conditions. These insights provide a foundation for optimising full-scale column designs, inform the selection of appropriate packing and solvent combinations, and guide process adjustments to maximise performance in real-world installations. The pilot plant's advanced instrumentation and flexible configuration helps move innovative packing technologies from pilot testing to commercial use. This aims to help new solutions meet operational requirements for energy efficiency, emissions reduction, and cost-effectiveness in large-scale PCCC projects.

### Case study 1: Economic savings in an NGCC power plant $CO_2$ absorber

Replacing conventional structured packing with Flexipac CP packing in a 1,200 MW natural gas combined cycle (NGCC) power plant represents a significant upgrade in carbon capture efficiency with lower capital expense. Traditionally, NGCC absorber columns are equipped with standard packing to handle approximately 7 million lb/hr of flue gas, equivalent to about 3.5 million tons/year of $CO_2$ emissions. However, conventional packing often requires larger column cross-sections and greater packing heights to achieve the necessary $CO_2$ removal rates, resulting in higher capital and operational costs.

By switching to Flexipac CP packing, NGCC plants benefit from a 15% reduction in packing height and a 6% reduction in column cross-sectional area compared to conventional designs. This translates to a capital savings of $4.5 million for the absorber and operational cost savings of $350,000 due to lower pressure drop. Flexipac CP packing delivers the same level of $CO_2$ removal with significantly less packing volume. This not only reduces costs for the vessel and associated components but also reduces installation time. Additionally, the reduced pressure drop across the flue gas blower before the absorber decreases electricity consumption, further lowering operational expenses.

In summary, replacing conventional packing with Flexipac CP structured packing yields measurable economic benefits, enhances process reliability, and is designed to support flexible compliance with environmental regulations. This upgrade enables NGCC plants to achieve sustainable, large-scale carbon capture while optimising both performance and cost.

### Case study 2: Design of a direct contact cooler

The direct contact cooler (DCC) plays a pivotal role in optimising thermal energy recovery and efficiently handling large gas flows and significant temperature drops, ensuring robust process reliability and effective heat transfer between upstream heaters and downstream operations. An important consideration when applying Flexipac CP structured packing to the DCC is the benefit provided by its advanced liquid spreading geometry, especially in systems where solvents or process fluids exhibit high surface tension. This innovative geometry enhances liquid distribution across the packing surface, overcoming wetting challenges that are common with high surface tension fluids. As a result, the system achieves more uniform mass and heat transfer, maintaining high efficiency even under demanding process conditions. This feature is particularly valuable in direct contact cooling applications, where consistent thermal performance and reliable operation are critical to overall plant efficiency. Specifically, for an 8 million lb/hr flue gas stream from an industrial process at 130°F, Flexipac CP structured packing is expected to deliver a 22% reduction in tower diameter and a 10% increase in capacity compared to the standard, conventional structured packing offering.

These reductions in tower diameter are primarily driven by the lower pressure drop associated with Flexipac CP packing, which enables the system to handle higher gas flow rates without requiring larger column sizes. The decreased pressure drop not only allows for a more compact design, but also leads to operational cost savings of $100,000 per year by reducing the energy required for gas movement through the column. Similarly, the smaller vessel requirements results in capital savings of approximately $500,000 by lowering the costs for the vessel and associated equipment while also simplifying installation and construction.

Building on these performance gains, Flexipac CP packing demonstrates how advanced packing solutions directly translate to operational flexibility and cost-effectiveness, with the reduced internal diameter and increased throughput enabling greater energy recovery and enhanced process capacity. By combining innovative packing technologies with precision-engineered column internals, operators can achieve consistent heat exchange, lower energy consumption, and robust handling of variable process loads.

## Large-scale columns

Given the large scale of these columns, the design and operation present engineering challenges that must be addressed to ensure reliable performance and efficient separation processes. As the columns increase in size, superior approaches to liquid and gas distribution, mechanical support, and installation precision become imperative. It is important to note that even with advanced packing, optimal performance cannot be achieved without a properly engineered internals design. The effectiveness of the packing relies on well-matched liquid and gas distribution systems, as inadequate or incompatible internals can significantly diminish efficiency and overall column performance. Advanced distributor systems, comprehensive computational fluid dynamics (CFD) analysis, and robust mechanical designs are essential not only to maintain uniform hydraulic behaviour but also to safeguard the integrity and operational efficiency of these large structures.

Implementing sophisticated large distributor designs can help promote more uniform liquid and gas distribution throughout mega-columns, which may positively influence separation efficiency and operational reliability. These advanced distributors are engineered to accommodate high flow rates and variable process loads, minimising maldistribution and channelling that can compromise performance. Accurate flow testing, both at pilot and full scale, validates distributor functionality by confirming even flow patterns and identifying potential areas for improvement. Proper levelling of distributor internals is equally essential, as any tilt or uneven placement can lead to significant maldistribution, undermining the effectiveness of even the most advanced distributor systems. Levelling ensures that liquid and gas are distributed evenly across the entire column cross-section, supporting optimal hydraulic performance and maintaining mechanical integrity in large-scale applications. By integrating meticulous distributor design with comprehensive flow testing, operators can achieve optimal hydraulic performance, safeguard mechanical integrity, and ensure consistent results in large-scale column applications.

Mechanical support and structural integrity are essential considerations in the design and operation of large absorber and cooler columns utilising advanced structured packing. These massive vessels must withstand substantial static and dynamic loads arising from process fluids, packing weight, and operational pressures. Robust mechanical supports, such as carefully engineered support beams and trusses, ensure that the packing remains securely in place under all process conditions, preventing deformation or collapse. Additionally, proper alignment and reinforcement of column shells and internals safeguard against vibration, thermal expansion, and mechanical stresses, thereby prolonging equipment life and maintaining reliable separation performance over extended operating periods.

Comprehensive CFD analysis further supports these operational improvements by providing detailed visualisation of flow patterns within the absorber and cooler columns. By integrating CFD insights with pilot-scale data, engineers can refine internal configurations, validate design assumptions, and anticipate operational challenges. These analyses would ensure that mega-column deployments maintain optimal liquid and gas distribution while maximising $CO_2$ absorption efficiency. This approach enhances the accuracy of scale-up calculations, strengthens process reliability, and builds confidence in the successful implementation of Flexipac CP structured packing across large industrial projects.

Effective post-combustion carbon capture mega-column projects require an integrated approach, addressing hydraulics, mass transfer, mechanical integrity, construction, logistics, and operations. Success depends on disciplined scale-up, proven design practices, and coordinated execution from fabrication to site.

## Conclusion

The advancement of structured packing technology marks a significant step forward in addressing the economic and operational challenges of industrial decarbonisation. By optimising the internal design of absorber columns, Flexipac CP structured packing enhances gas-liquid contact, which directly improves $CO_2$ capture efficiency. This heightened efficiency may lead to lower residual $CO_2$ emissions in treated gas streams, which can support compliance with stringent environmental regulations and advancing sustainability objectives. Optimal packing not only reduces pressure drop but also enables more effective mass transfer. The enhanced mass transfer characteristics allow for a lower solvent circulation rate, which in turn decreases the thermal energy required for solvent regeneration. These reductions in regeneration duties contribute to significant energy savings and operational efficiency, making large-scale carbon capture projects more economically viable.

Through rigorous pilot-scale testing and real-world case studies, Flexipac CP packing has demonstrated substantial improvements, including up to a 25% increase in efficiency over conventional packing. These benefits translate directly into measurable cost savings, reduced emissions, and improved process reliability for large-scale carbon capture applications. By integrating advanced mass transfer equipment, operators can optimise column designs, minimise spatial requirements, and confidently adapt to evolving environmental standards.

As industries aim for decarbonisation, innovations like Flexipac CP structured packing can help reduce emissions, solvent use, and energy needs for regeneration.

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## Further reading


Nouri, E., Raouf, F., Jamali Alyani, S. et al. Carbon dioxide capture and utilization in post-combustion: a review. *Environ Sci Pollut Res* 32, pp.14,351–14,382 (2025). [Online] Available at: https://doi.org/10.1007/s11356-025-36546-6.

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