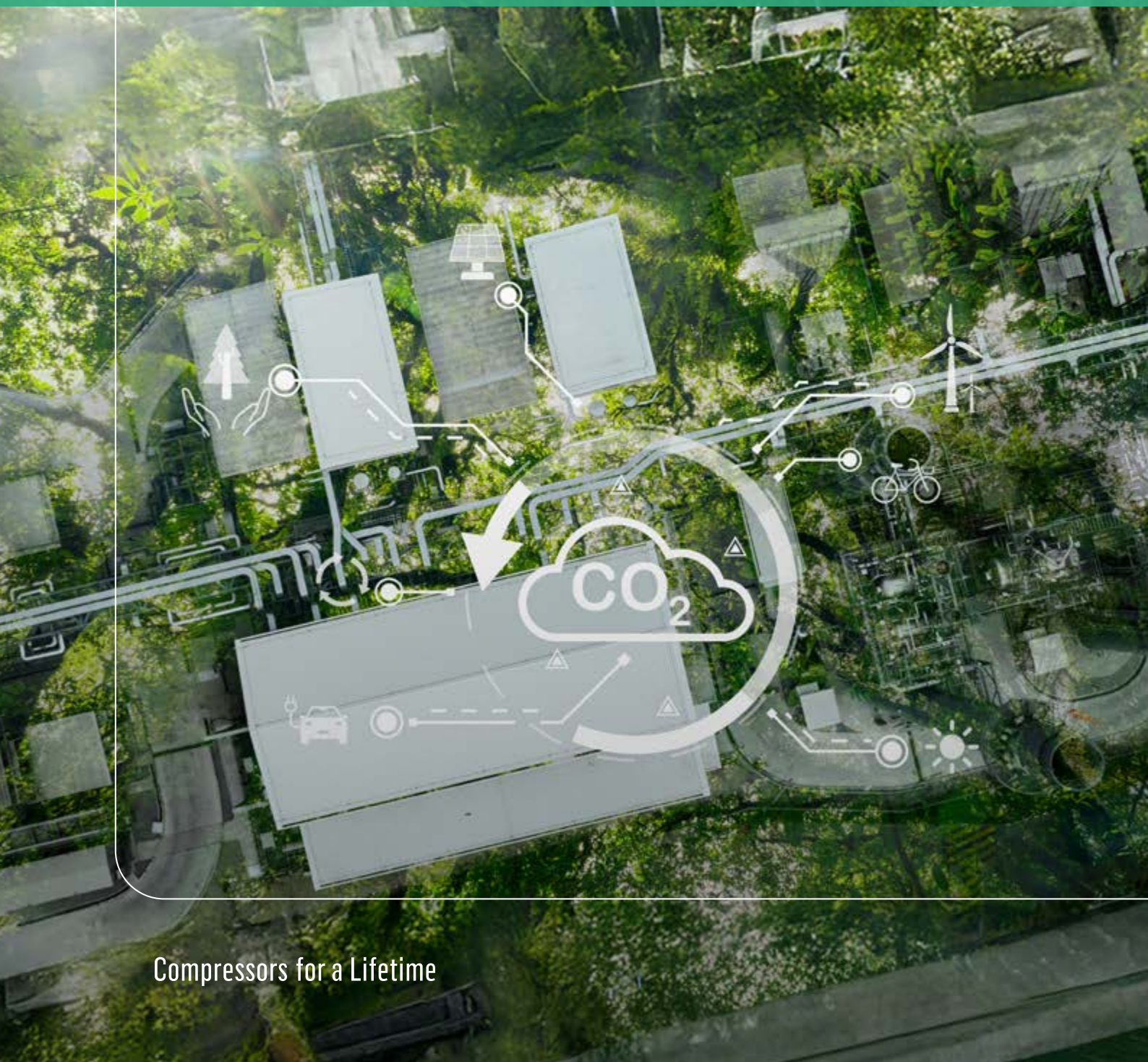
Burckhardt Compression

Minimized operating cost in carbon capture, utilization and storage

Efficient compression solutions for CO_2



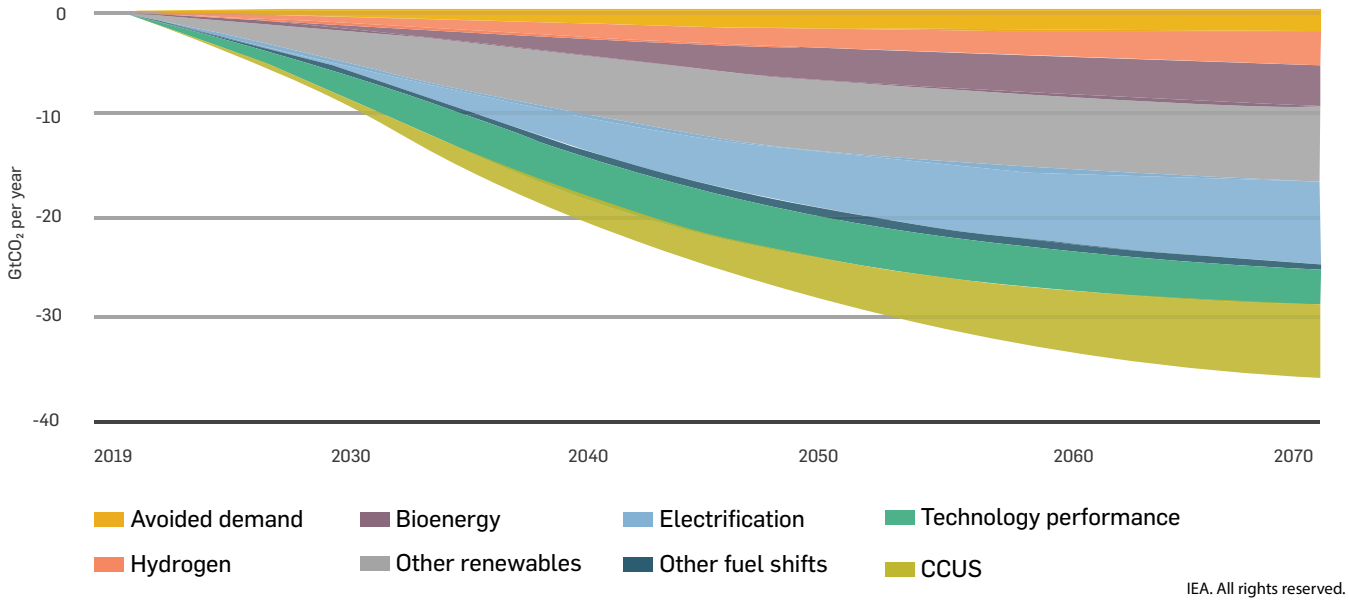
Compressors for a Lifetime

CCUS's role in mitigating climate change

As countries push to balance energy security with aggressive decarbonization goals, every major energy sector – nuclear, solar, wind, hydropower, coal, natural gas and oil – is being reshaped. In this evolving landscape, carbon capture, utilization and storage (CCUS) stands out as a critical pathway to a low carbon future.

CCUS significantly reduces greenhouse gas emissions from hard-to-abate industries such as cement, steel and chemical, but most importantly from fossil fuel-based power generation facilities. By capturing CO_2 at the source and either storing it underground or repurposing it for industrial use, CCUS mitigates the environmental impact of existing infrastructures while supporting industrial competitiveness. When deployed at scale, CCUS complements renewable energy expansion and accelerates progress toward net-zero goals, making it indispensable for global climate strategies.

CO_2 emissions reductions in the energy sector in the Sustainable Development Scenario relative to the Stated Policies Scenario



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Challenges and opportunities

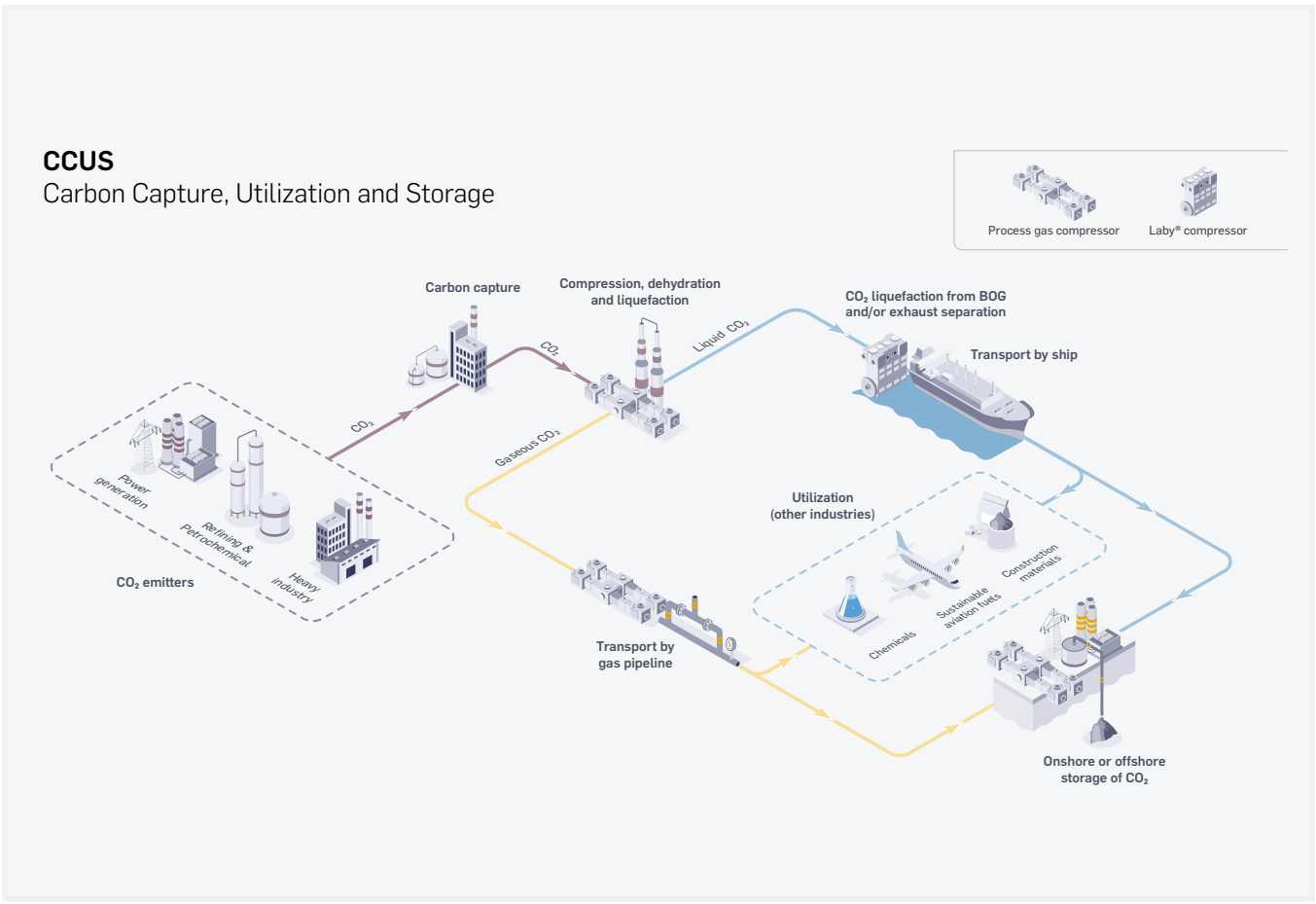
Despite its possibilities, realizing the full potential of CCUS requires overcoming significant challenges. High capital costs, complex and evolving regulatory frameworks and the need for extensive CO_2 transport and storage infrastructure continue to constrain widespread adoption. Public acceptance and long-term liability of stored CO_2 demand careful governance and transparent risk management.

At the same time, opportunities abound. Supportive policy incentives, carbon pricing mechanisms and collaborative investment models are driving the economic case for CCUS projects. Technological innovation combined with economies of scale are expected to reduce costs and enhance efficiency, paving the way for CCUS to become a mainstream climate solution. Soon, CCUS will play a pivotal role in bridging the gap between current emissions and future climate goals. Realizing that role, however, depends on overcoming the practical challenges of operating CCUS systems.

Operating a capture facility

The operation of carbon capture facilities introduces its own set of technical and operational complexities. Capture systems, particularly those based on amine solvents, are subject to degradation under thermal and oxidative stress, leading to increased solvent replacement costs and unplanned downtime. Also, impurities in flue gas such as sulfur oxides, nitrogen oxides and particulates contribute to fouling and corrosion within absorber columns, necessitating frequent maintenance interventions. Variability in feed gas composition further complicates operations, as fluctuating CO_2 concentrations can reduce capture efficiency and place additional demands on process control systems.

These challenges are compounded by the high energy requirements of capture, where solvent regeneration and, critically, CO_2 compression impose a significant energy penalty on the host facility. As captured CO_2 must be compressed from near-atmospheric conditions



to transport or storage pressures, compression becomes one of the most energy-intensive and operationally sensitive steps in the process. Ensuring the reliability and efficiency of critical equipment like compressors and heat exchangers is therefore essential, as failures can disrupt operations for extended periods.

Finally, the handling of CO_2 at elevated pressures introduces safety considerations, requiring robust system design and strict operational protocols to mitigate risks such as leaks and asphyxiation.

Transporting CO_2 and integrity across distances

Beyond the capture facility, safety considerations become even more pronounced during the transport of CO_2 to utilization or storage sites. As a critical link in the CCUS value chain, CO_2 transport must ensure that the gas remains stable, contained and within tightly controlled thermodynamic conditions over long distances and varying environments.

Pipelines remain the primary solution for large-scale, continuous CO_2 transport, with the gas typically maintained in a dense or supercritical state (above 74 bar and 31°C) to optimize efficiency. Sustaining these conditions requires precise pressure and temperature control, as even minor deviations can result in phase changes and the onset of two-phase flow, impacting both flow assurance and system integrity. Compression plays a central role in this process, not only in initially bringing CO_2 to transport conditions but also in maintaining pressure along the pipeline through intermediate booster stations.

CCUS project developers and engineers must also address pipeline impurities. Trace amounts of water, sulfur compounds, or other contaminants can lead to corrosion and hydrate formation. Such impurities necessitate rigorous gas conditioning upstream and place added demands on compression systems. From a safety perspective, CO_2 pipelines introduce unique risks, including difficult leak detection and the potential for running ductile fractures in the event of rupture, requiring robust design standards and continuous monitoring.

While pipelines are the backbone of CO_2 transport, ship, rail, truck and barge are also important for offshore storage and regions without pipeline infrastructure. These alternative transportation methods introduce additional complexities, including cryogenic handling, liquefaction energy requirements and boil-off gas (BOG) management. Across all modes, maintaining CO_2 in the appropriate phase relies on effective compression and pressure management.

As CCUS expands globally, cross-border transport can introduce further issues. Differences in national standards and infrastructure readiness can complicate project development, requiring coordinated investment and governance. Regardless of transport method or geography, the ability to reliably compress, condition and manage CO_2 under varying conditions remains fundamental to ensuring safe and efficient movement across the CCUS network.

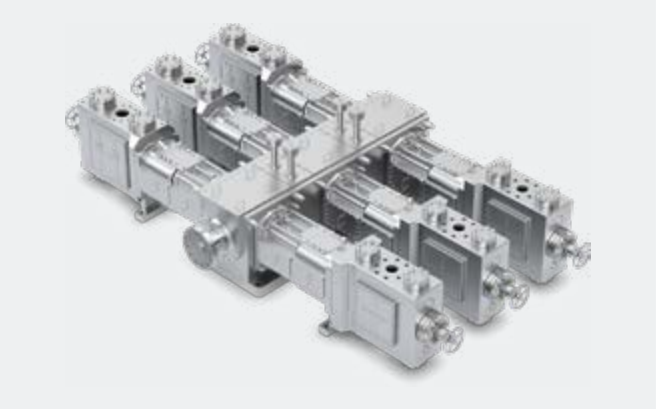
Reciprocating compression technology solutions for CCUS

The challenges associated with capturing, transporting and storing CO_2 place increasing demands on compression systems. From managing low-pressure inlet conditions at capture sites to maintaining dense-phase transport and achieving high-pressure injection, compressors must deliver consistent performance, high efficiency and long-term reliability under variable and often demanding conditions.

Reciprocating compression technology is a proven and highly effective solution to demanding CCUS requirements. Its ability to handle high pressure ratios, variable flow conditions and a wide range of gas compositions makes it a critical enabler across the CCUS value chain. Unlike other compression technologies, reciprocating compressors can be precisely configured to match specific process conditions, allowing operators to optimize performance while minimizing energy consumption and operational risk.

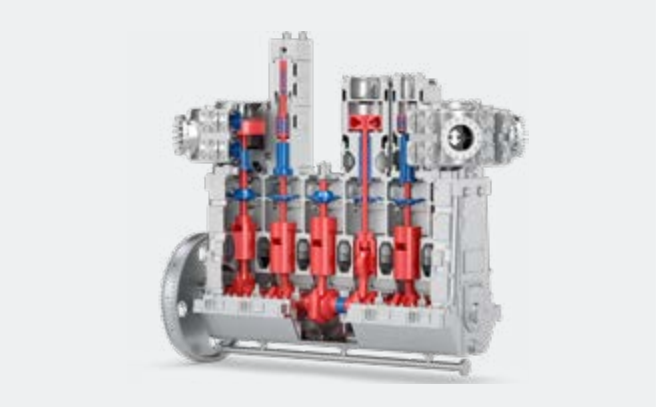
Burckhardt Compression has pioneered a diverse range of reciprocating compressor designs, featuring advanced piston sealing mechanisms including piston rings, plunger with cylinder rings and labyrinth (Laby®) sealing systems. With this range of expertise, operators can confidently choose compressor solutions tailored to their unique process requirements, from gas composition to overall operations.

For applications requiring robust, continuous-duty performance, horizontal, balanced opposed (ring-type) compressors provide high efficiency and mechanical stability. These fully balanced designs minimize vibration and mechanical stress, supporting long service intervals and reliable operation in demanding environments such as CO_2 transport and injection.



Fully balanced high-speed compressor

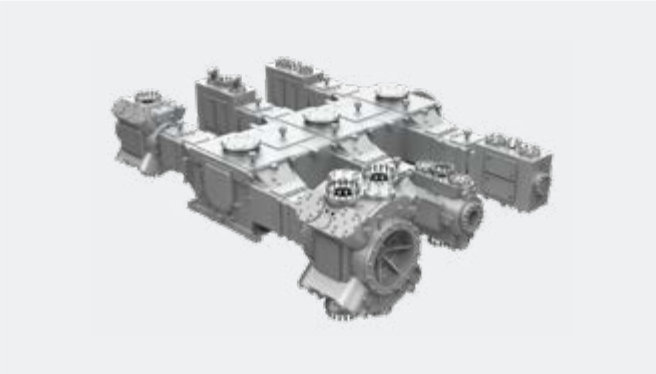
In contrast, labyrinth (Laby®) compressors offer oil-free compression, an option preferred by operators who prioritize gas purity above all. The non-contact sealing design reduces wear, extends maintenance intervals and enhances operational reliability, key considerations in CCUS systems where uptime and consistency are paramount.



Laby-GI compressor

Process gas compressors further extend this capability by enabling the handling of complex gas streams and high-pressure requirements across capture, transport, and storage stages. Whether compressing CO_2 from near-atmospheric conditions or boosting pressure for pipeline transport and injection, these systems are engineered to operate efficiently across a wide range of conditions while maintaining strict safety and performance standards.

In a value chain where compression is not optional but foundational, selecting the right technology plays a decisive role in enabling safe, efficient and scalable CCUS deployment.



Process gas compressor

Tailored compressor solutions across the value chain

The diversity of operating conditions across the CCUS value chain requires tailored compressor solutions that align with each stage from initial capture to permanent storage. Each stage presents distinct technical demands and selecting the appropriate compression technology is essential to ensuring efficiency, reliability and long-term performance.

At the capture stage, CO_2 must be compressed from near-atmospheric pressure, while downstream processes demand progressively higher pressures for transport and injection. Intermediate hubs and storage terminals (onshore and offshore) introduce additional complexity, requiring compressors that can operate reliably across distributed networks. Further, effective compression is essential for addressing impurities, corrosion risks and leak prevention, to ensure integrity of the entire system.

CO_2 liquefaction

When CO_2 is transported as a liquid, required for cryogenic shipping and certain storage applications, compression is an essential first step in the liquefaction process. After capture, CO_2 is typically at low pressure and must be compressed to a range of 15–25 bar for liquefaction and sometimes up to 80–100 bar for transport and storage.

This process requires multi-stage compression with intercooling to manage heat and optimize energy consumption. Compressors must also be designed with corrosion-resistant materials and advanced sealing systems, as the presence of water can lead to carbonic acid formation. Integrated drying and filtration are essential to prevent hydrate formation and ensure stable operation. Compliance with industry standards such as API 618 further ensures that compressor systems meet stringent requirements for reliability and safety.

CO_2 pipeline transportation

As previously mentioned, pipeline remains the backbone of large-scale CCUS infrastructure, with CO_2 typically transported in a supercritical thermodynamic state to maximize efficiency. Achieving and maintaining supercritical conditions relies on precise compression and pressure to ensure stable, high-density flow and efficient pipeline operation.

CO_2 BOG and evaporation in transport

In cryogenic transport scenarios, such as ship-based CO_2 movement, BOG management becomes a critical consideration. CO_2 is normally transported as a liquid at temperatures around –50 °C and pressures of approximately 6 to 8 bar. Under these conditions, heat ingress and pressure fluctuations cause a portion of the liquid to vaporize, increasing pressure within storage tanks and creating both safety and economic hazards.

Compression systems play a key role in managing BOG through re-liquefaction or recompression strategies. Vaporized CO_2 can be compressed and cooled back into liquid form, preserving product and maintaining pressure stability. Alternatively, it can be compressed for storage or reintegration into the transport system. These applications require compressors capable of handling low-temperature conditions, variable flow rates and intermittent operation.

CO_2 storage and injection

For geological storage, CO_2 must be compressed to high pressures, often exceeding 100 bar to overcome reservoir pressure and ensure efficient placement in porous rock formations. Compressors working at this stage of CCUS maintain continuous-duty operation for stable injection operations.

Multi-stage compression with intercooling is typically used to manage heat build-up and efficiency. Simultaneously, materials and sealing systems must withstand prolonged exposure to high-pressure CO_2 environments to directly influence overall reliability. Integrated dehydration and impurity removal further protect system integrity. Given the continuous nature of injection operations, selecting the right compression technology directly impacts both project uptime and long-term storage performance.

Utilization: expanding pathways for CO_2 value

While this paper focuses on compression across capture, transport and storage, it is important to recognize that CO_2 utilization is an emerging and expanding market within CCUS. By converting CO_2 into valuable products, utilization creates additional demand for reliable compression systems to support process integration and material handling.

Demanding operating conditions

CCUS applications place compression systems in highly demanding, variable operating conditions. These conditions are particularly pronounced when handling CO_2 in its supercritical state, where fluid behavior differs significantly from conventional gases and directly impacts a compressor.

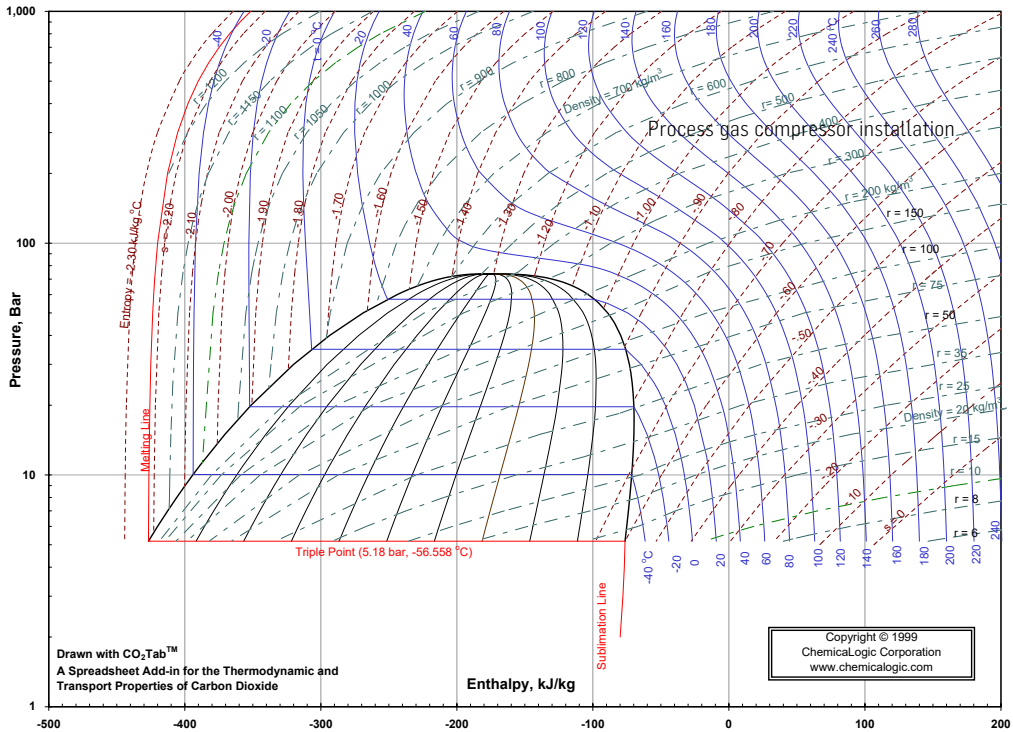
In the supercritical state, CO_2 exhibits unique thermodynamic behavior. Near the critical point (74 bar, 31°C) density, viscosity and compressibility become highly sensitive to small changes in temperature and pressure. As illustrated in the Mollier diagram, small variations in temperature or pressure lead to disproportionately large changes in fluid properties, particularly density.

A relatively small temperature reduction at constant pressure can significantly increase CO_2 density by approximately 50%. This directly influences mass flow, volumetric efficiency and compression power requirements.

In a dynamic operating environment with rapidly changing gas properties, compression technology must withstand the demands. Systems have to maintain stable, efficient operation despite continuous changes in thermodynamic conditions. It is something not all compressor types can achieve effectively and is precisely why reciprocating compressors offer a decisive advantage.

Why reciprocating compressors excel in CCUS

Reciprocating compressors operate as positive displacement machines, compressing a fixed volume of gas per stroke regardless of changes in density, pressure, or temperature. This characteristic enables stable performance across a wide operating range, even under the highly variable conditions typical for CCUS. Capacity can be adjusted through speed variation and advanced volume control methods such as clearance pockets or valve unloading, allowing operators to respond to changing process conditions without significant energy loss. As a result, reciprocating compressors maintain high performance not only at design conditions, but also during off-design operation which is an essential requirement in real-world CCUS systems.



Carbon Dioxide: Pressure - Enthalpy Diagram

This advantage becomes even more pronounced when compared to centrifugal compressors. Centrifugal compressors are designed to operate within a narrow performance window defined by a specific design point. Deviations in suction pressure, temperature, or gas composition require throttling or bypass control to maintain stability, which reduces efficiency and increases operating costs. In contrast, reciprocating compressors remain largely unaffected by such variations, maintaining consistent compression performance without the need for energy-intensive control strategies. Their compression process is also closer to isentropic, resulting in lower overall energy consumption, particularly at the high compression ratios required for CO_2 liquefaction, pipeline



transport and geological storage.
In supercritical CO_2 applications, where density can vary significantly with small changes in operating conditions, flexibility is paramount. Reciprocating compressors can handle a wide range of gas densities without fundamental changes in design or performance. This allows them to accommodate fluctuations in mass flow and power requirements while maintaining high energy efficiency, supported by low leakage rates and minimal valve losses. The result is a compression solution that delivers not only superior operational stability, but also lower lifecycle costs for CCUS.

Reciprocating compressor availability

For CCUS success, plant operators and engineers need more than efficiency and flexibility. Availability for modern compression systems goes far beyond traditional reliability, availability and maintainability (RAM) metrics. In critical applications where CO_2 compression underpins continuous capture, transport and injection operations, availability becomes a defining performance metric. Achieving availability levels approaching 97% is possible and requires a holistic approach that combines trusted compressor design with proactive lifecycle management. In turn, CCUS project leaders increasingly evaluate compressors not only on technical design, but on their ability to deliver sustained, predictable availability over decades of operation.

Leveraging the inherent adaptability and durability of reciprocating compressors, Burckhardt Compression has developed an enhanced availability concept built around a comprehensive “customer toolbox.” The toolbox minimizes unplanned downtime, reduces mean time to repair (MTTR) and supports consistency by offering:

- Preventive maintenance planning
- Emergency response readiness
- Spare-parts availability
- Monitoring systems
- Training and skills development

Complemented by a global service network and decades of application experience, Burckhardt Compression's availability-focused toolbox allows operators to maintain high system uptime while protecting safety, asset integrity and ROI.

Decades of proven experience in CO_2 compression

Burckhardt Compression has been compressing industrial CO_2 for decades. As early as 1954, the company supplied some of the first CO_2 compressors for commercial use to the Miller Brewing Company in Milwaukee, USA and Brauerei Schützengarten in St. Gallen, Switzerland. As the industry evolved, Burckhardt Compression expanded its CO_2 portfolio to serve the fertilizer and chemical industry sectors.

Burckhardt Compression's depth of experience is reflected in a globally installed base of more than 500 CO_2 and CCUS-related applications, ranging from small-scale industrial capture to large, integrated management systems. The cumulative operational knowledge gained from these projects continues to influence compressor design, materials selection, sealing technologies and service strategies, ensuring that CCUS solutions are grounded in proven performance rather than theoretical assumptions.

Burckhardt Compression

We love to provide services that matter. Hands-on.

Personal, passionate, powerful: this defines us. Meet technical experts with decades of engineering excellence and an outstanding customer-first mindset. Rooted in over 180 years of OEM expertise, we offer the full range of services for your compressors and auxiliaries throughout the entire lifecycle – regardless of brand or challenge.

We put safety first in all we do and support you with energy-efficient, sustainable solutions. With a strong local presence around the globe, we focus on building reliable and trusted partnerships that last, ensuring mutual success. At the forefront of digital innovation, we are constantly pushing boundaries to deliver faster, more efficient and advanced solutions that prioritize the highest safety standards and support your sustainability objectives. As a global leader in our field, we support you with unmatched engineering know-how.



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