

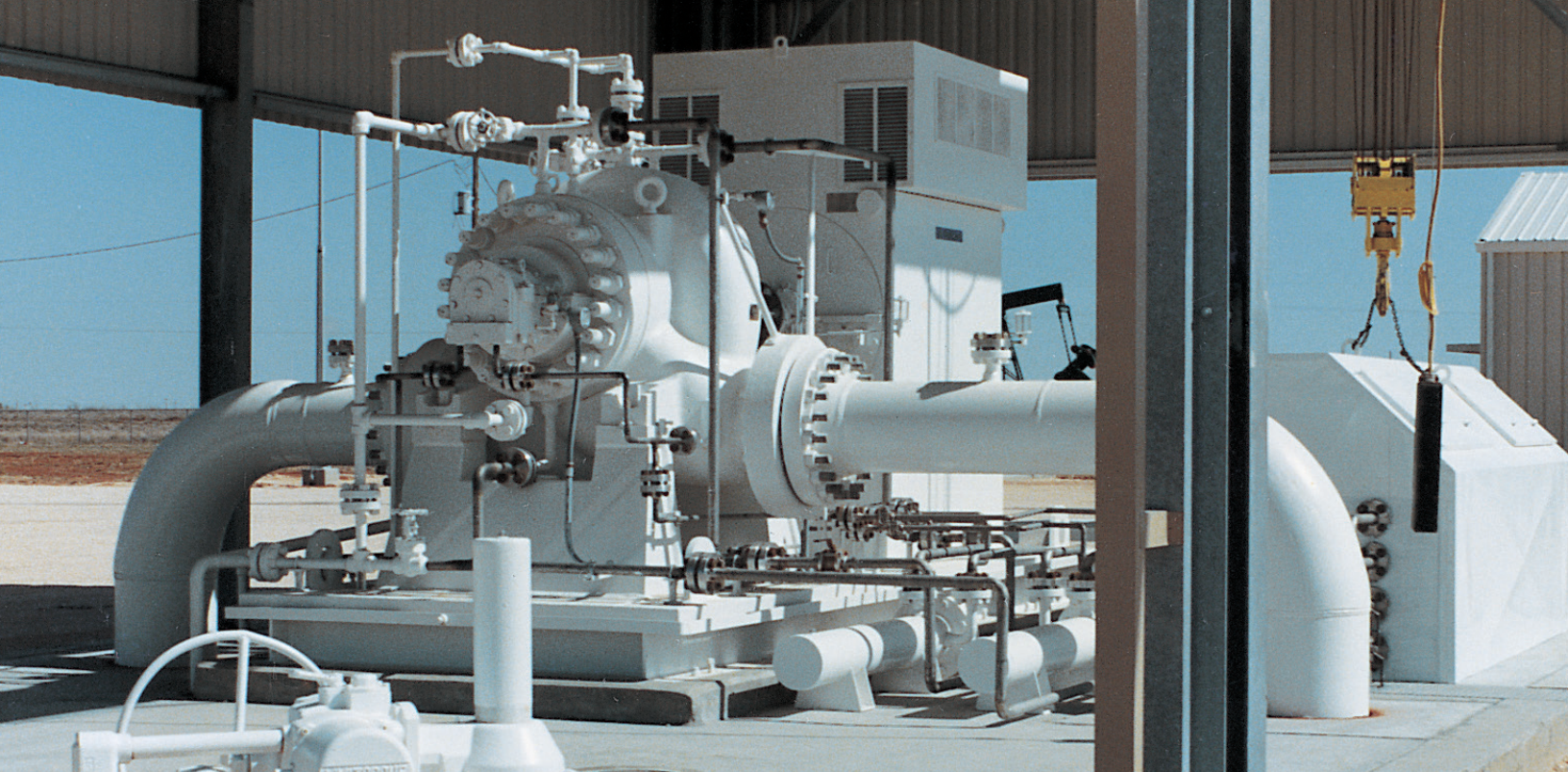


Pumping Solutions for Carbon Capture, Utilization and Storage

Leading technologies and expertise to advance your decarbonization goals



Experience In Motion



CCUS pumping solutions for a carbon-constrained world

Carbon capture utilization and storage (CCUS) technologies offer significant opportunities for industry and society to avoid emitting carbon dioxide (CO₂), a greenhouse gas (GHG) known to contribute to climate change.

That's why Flowserve is dedicated to helping customers decarbonize processes and plants across industries. We have the technical expertise, industry-leading product portfolio and advanced support services to impact the carbon footprint of industry by reducing emissions, lowering energy use, and improving mechanical and process reliability.

Accomplish your energy transition goals with a proven partner

We understand how pumps, valves, seals and automation should work in complete systems. As a result, Flowserve can help you engineer, design, commission and maintain end-to-end CCUS solutions so they perform optimally.

In 1984, Flowserve pioneered the use of pumps for high-pressure CO₂ pipeline and injection services. Later, we became the first to use dry gas seals in dense phase CO₂ pumps. In addition, we possess unsurpassed experience in pumping the many solvents used to capture CO₂.

Leverage our global resources and proven product portfolio for the capture, transportation, storage and underground injection of CO₂ to accomplish your decarbonization goals.

Pumping systems to enable your CCUS objectives

Flowserve offers a wide range of pumping systems to meet CCUS application requirements. From pre-engineered, engineered and special purpose solutions, Flowserve pumps comply with — or even exceed — the most stringent industry standards and certification requirements, including:

- API 610
- ASME (ANSI) B73.1
- ISO 2858
- ISO 5199
- Hydraulic Institute



Solutions for the entire CCUS value chain

For more than two centuries, Flowserve has served industries requiring solutions that add value and reduce costs throughout the lifecycle of CCUS applications across industries and especially in the following:

- Oil and gas processing
- Cement manufacturing
- Power generation
- Steel manufacturing
- Chemical processing
- Fertilizer processing

We provide our CCUS partners with the know-how to respond to changing marketplace and regulatory conditions.

Flowserve works with customers to improve efficiency, maximize throughput, and control process quality. Whether you need equipment upgrades, on-site technical assistance or broader design, engineering and project planning capabilities with full turnkey responsibility, Flowserve delivers professional, reliable results.

Detect, diagnose and quickly respond

Successful CCUS projects will need more than engineered-to-order systems. In addition to providing the industry's most complete flow control solutions portfolio, Flowserve introduced RedRaven, an end-to-end internet of things (IoT) solution encompassing sensors to cloud architecture, condition monitoring and predictive analytics services.

CCUS operators can use RedRaven to monitor thousands of assets over sprawling facilities reliably and cost-effectively.

With real-time RedRaven monitoring, plant personnel and Flowserve technicians can view aggregated data to make decisions on-site. Our monitoring center along with our team of service and support personnel can provide you with insights, alerts and recommendations.

With RedRaven, you can proactively maintain CCUS systems to avoid unplanned downtime.

Driving decarbonization technologies

Actions that decarbonize operations can enable companies to achieve increasingly ambitious net-zero goals. By choosing Flowserve's Energy Advantage Program, you can accelerate your energy transition plans quickly and cost-effectively.

We provide a holistic flow control approach aimed at helping you reach your carbon reduction goals and lowering your total cost of ownership (TCO).

You can utilize Flowserve's engineering expertise, systematic data-driven evaluation process, and complete offering of proven products and services. As your partner, Flowserve can enable you to drive increased energy efficiency through the optimization of flow control equipment power consumption.

Flowserve's offerings through the Energy Advantage Program can also reduce your carbon emissions, improve plant productivity and reliability, and provide operational savings.

And, through our Carbon Advantage Program, companies can optimize decarbonization projects while balancing the economic impacts on operations.





For decades, Flowserve has been at the forefront of the development of process pump technologies to capture CO₂.

CO₂ capture technologies

The process technologies to capture CO₂ have been proven in the gas processing, chemical and petroleum industries. Flowserve has worked alongside our CCUS customers every step of the way for more than 50 years.

With the growing worldwide emphasis on curtailing and regulating GHG, CO₂ capture technologies are being applied on a much larger scale to fossil fuel power stations, refineries and general industrial manufacturing such as steel mills and plants making cement, fertilizer and even gray and blue hydrogen. To meet environmental, safety and governance (ESG) objectives, companies will need to install CO₂ capture absorption trains with reliable pumping solutions.



Experience, technology and support you can trust

With one of the largest installed bases of CO₂ solvent process pumps in the world, Flowserve has successful experience meeting highly challenging applications. From initial pump selection or design to aftermarket support, you can count on Flowserve for your carbon capture needs. We offer:

- The most complete line of process pumps, including high-efficiency units for CO₂ services
- Customized diagnostics that improve efficiency, reduce downtime, and optimize lifecycle costs
- Expertise in the application of advanced materials and surfacing technologies well-suited for the peculiarities of dense phase CO₂. These include selective hardening and direct laser disposition (DL) overlays and ceramic coatings. It also includes the use of metallic laser hardening as well as non-metallic materials (such as Graphalloy®) on wear parts to compensate for the low lubricity of CO₂.
- Our large global service network provides parts, repairs and maintenance as well as installation and commissioning. It also boasts unrivaled experience performing hydraulic re-rates and upgrades, regardless of OEM.

® Graphalloy is a registered trademark of the Graphite Metallizing Corporation.

Success story

Predictive analytics system improves Benfield plant reliability

Challenge

An ammonia/urea facility was experiencing recurring failures on its lean Benfield solution pumps used to remove CO₂ from process gas. Shaft failures were occurring every six to nine months, costing the plant hundreds of thousands of (U.S.) dollars in maintenance and downtime. A study by Flowserve confirmed that gas foaming created vibration and caused the shafts to fail due to fatigue.

Solution

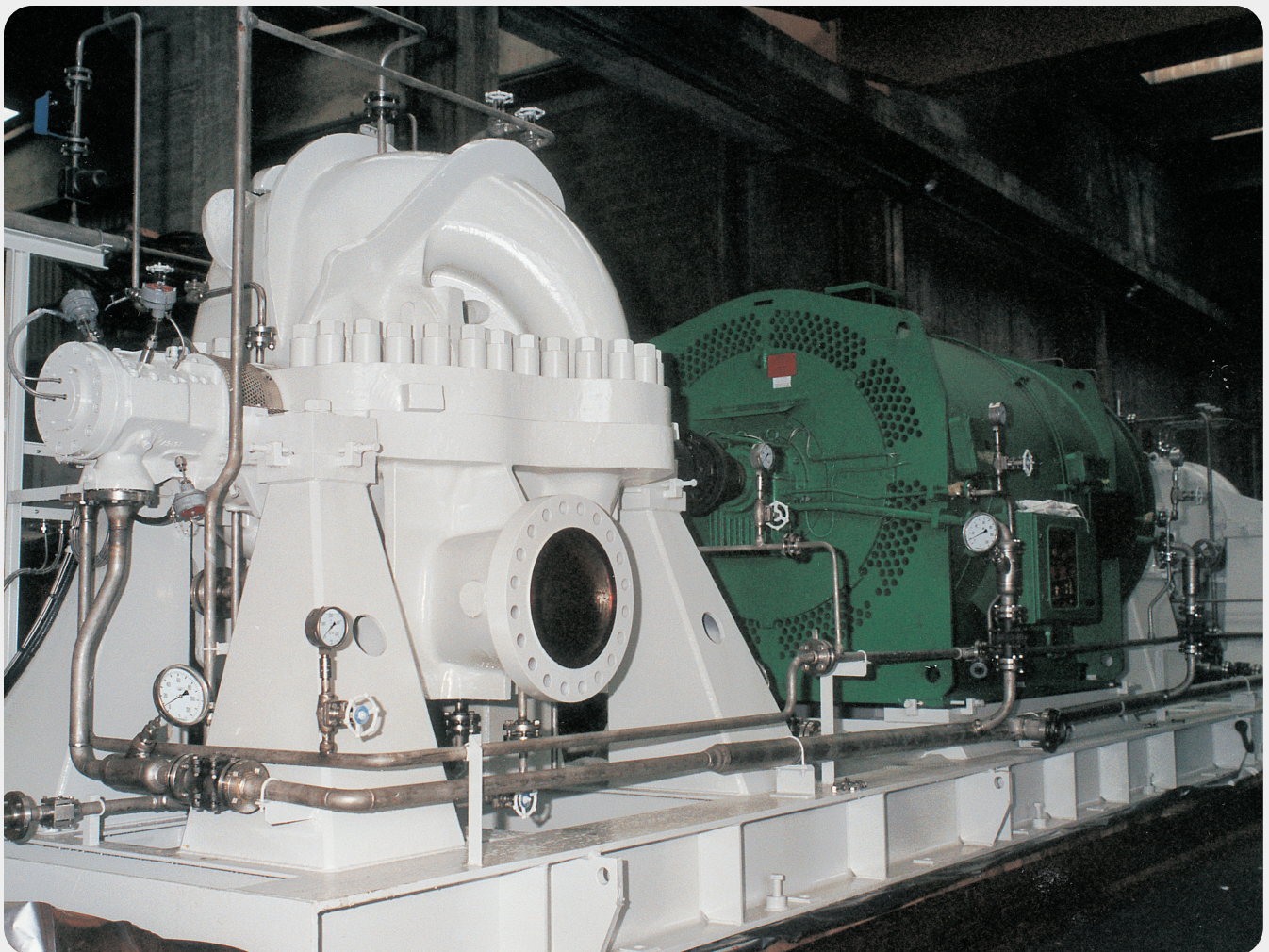
Flowserve worked with the customer to design application-specific predictive analytics to identify the onset of aeration in the system by continuously monitoring operating conditions

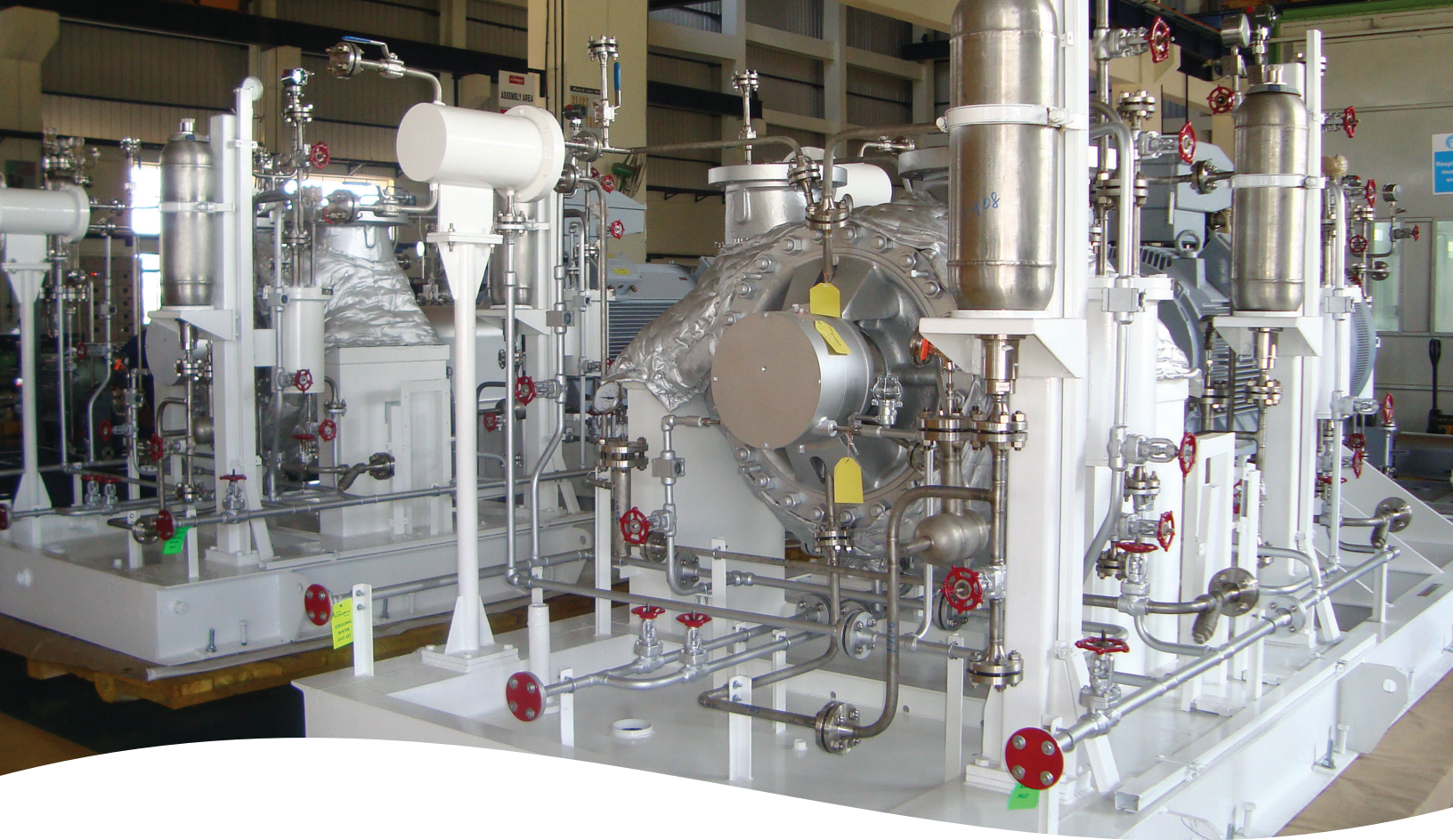
of the Benfield pumps. Flowserve also designed the hardware needed to see alerts at the pump and in the control room, making operators aware that corrective action was needed.

Results

The monitoring system lengthened the mean time between failure (MTBF) of the pump shafts to more than three years. This significantly reduced the lifecycle cost of the Benfield solution pumps.

To learn how Flowserve RedRaven condition monitoring and predictive analytics can improve your equipment and system reliability, visit www.flowserve.com/redraven.





Pumps for capturing CO₂

Whether utilizing pre-combustion or post-combustion technologies with amines, ammonia or other solvents, Flowserve can provide proven pumps in numerous metallurgies and configurations for all CO₂ capture applications.

ANSI, ISO and API process pumps

Many designs available: low flow/high head, self-priming, dynamic sealing, recessed impeller, in-line and centerline mounted (HPX, Mark 3™, Mark 3 ISO and PVML)

Typical process parameters

- Flows to 5,000 m³/h (22,014 gpm)
- Heads to 350 m (1,148 ft)
- Pressures to 80 bar (1,160 psi)

Slurry and solids-handling pumps

Overhung horizontal and vertical configurations; back end pullout design (MND and FRBH)

Typical process parameters

- Flows to 17,500 m³/h (77,000 gpm)
- Heads to 100 m (328 ft)
- Pressures to 14 bar (203 psi)



Durco® Mark 3

Heavy-duty, axially split, between bearings pumps

Double volute casing; hydraulically balanced, double-suction impeller (LNN, UZDL and LPN)

Typical process parameters

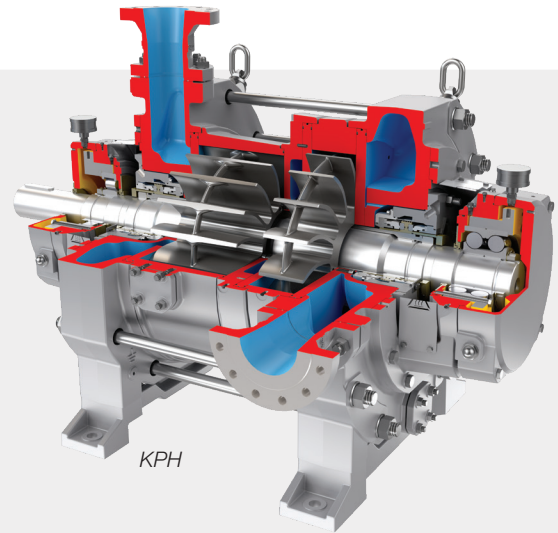
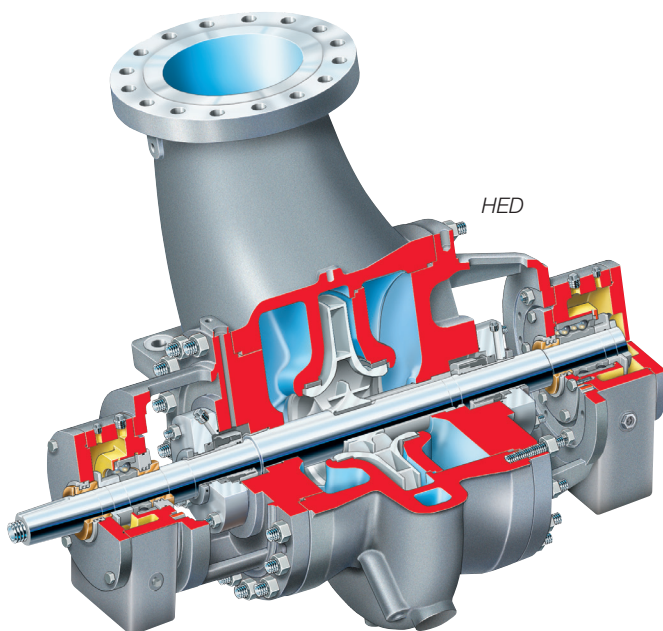
- Flows to 30,000 m³/h (132,000 gpm)
- Heads to 685 m (2,250 ft)
- Pressures to 64 bar (910 psi)

Heavy-duty, radially split, double-suction process pumps

API 610 (BB2), latest edition; double volute, centerline supported, self-venting casing (HDX and HED)

Typical process parameters

- Flows to 5,000 m³/h (22,000 gpm)
- Heads to 650 m (2,100 ft)
- Pressures to 100 bar (1,500 psi)



Liquid ring pumps and compressors

SIHI® KPH liquid ring compressors from Flowserve are designed to compress different kinds of gases and vapors, including CO₂. They are well-proven and most commonly used in applications where safety, reliability and special process conditions are required. They are able to operate under the most severe process conditions and can use any type of service liquid. This makes SIHI liquid ring compressors unique for special applications where process contamination is prohibitive.

Benefits

- Compliance with API 681
- Best-in-class isothermal efficiency
- Discharge connection can be selected on either right or left side
- Adjustable range of service liquid consumption
- Smallest dimensional footprint
- Integrated rotor support
- Sturdy between bearings design
- Low vibration

Typical process parameters

- Suction capacity to 2,100 m³/h (1,236 cfm)
- Compression over-pressure to 10 barg (145 psig)
- Maximum gas inlet temperature to 100°C (212°F)

Flowserve pioneered the use of centrifugal pumps for transportation of supercritical dense phase CO₂ in pipelines and injection for enhanced oil recovery and underground sequestration.



CO₂ transportation and storage

Pipeline

Once captured, the CO₂ must be transported to a permanent storage site. The most economical method for transporting large volumes of CO₂ is via pipeline.

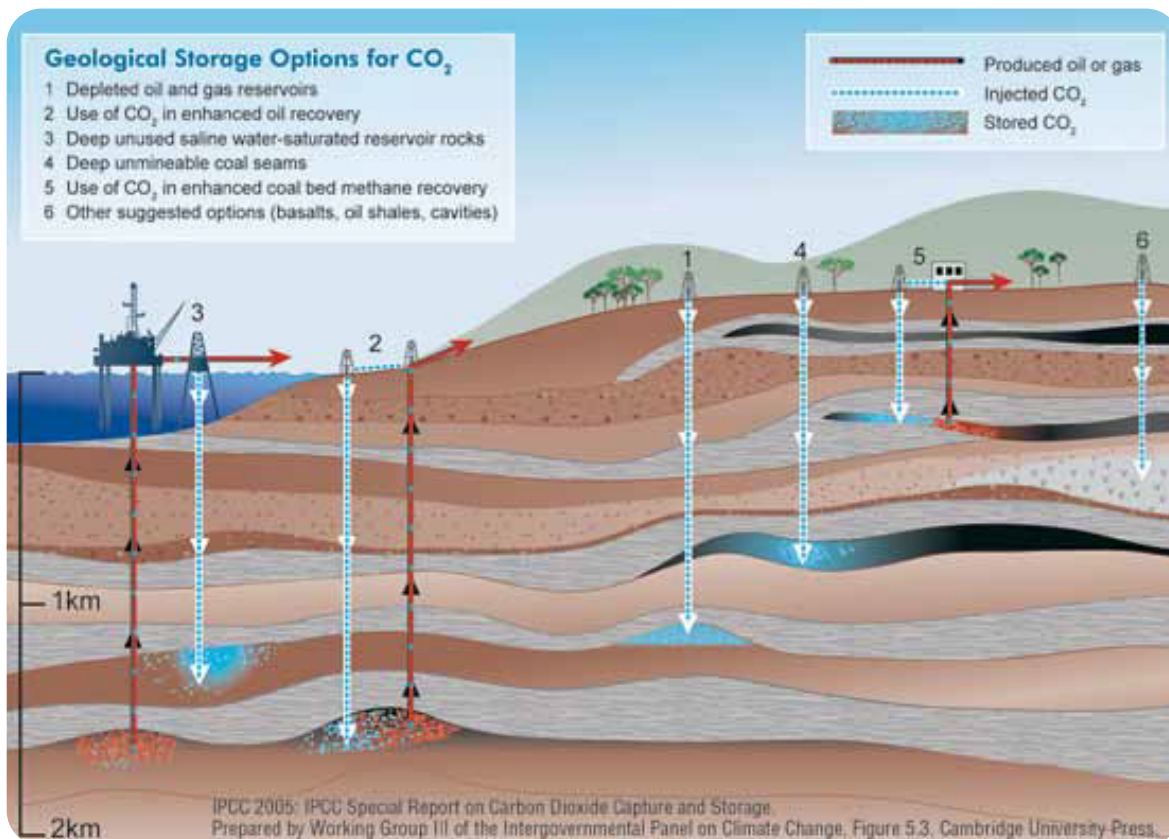
To make this possible, the CO₂ is converted into a high-pressure, supercritical fluid called *dense phase*. In this phase, the CO₂ behaves more like a liquid than a gas, enabling it to be pumped.

Flowserve offers radially and axially split pumps that are ideal for dense phase CO₂ transportation.

Injection

The leading methods of sequestration involve injecting dense phase CO₂ into geological reservoirs. The most economically viable of these is enhanced oil recovery (EOR), where CO₂ is injected into active oil fields to increase production.

Long-term storage can be accomplished by injecting captured CO₂ into underground saline aquifers and depleted oil and natural gas reservoirs. Regardless of the method, Flowserve offers high-pressure, axially split pumps and highly engineered, high-energy, double-case pumps for injection.



Overview of geologic storage options



Pumps for CO₂ transportation and storage

As the world's leading supplier of CO₂ pipeline and injection pumps, Flowserve offers several pump models that have demonstrated proven reliability in these critical applications:

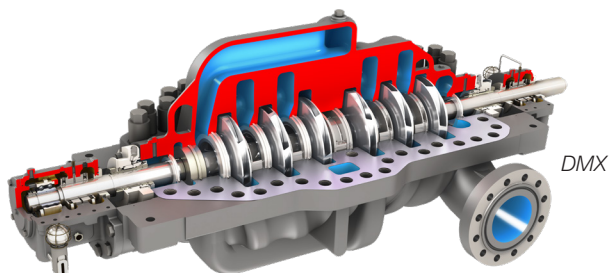
- Single and multistage pipeline and injection pumps
- High and ultra-high pressure barrel pumps for injection services
- Sealing solutions using liquid or dry gas seals

Heavy-duty, radially split, double-suction, single-stage process pump

API 610 (BB2), latest edition; between bearings, double volute casing (DVSR)

Typical process parameters

- Flows to 6,585 m³/h (29,000 gpm)
- Heads to 330 m (1,080 ft)
- Pressures to 260 bar (3,750 psi)



Heavy-duty, high-pressure, axially split, multistage API pump

API 610 (BB3), latest edition; between bearings, near centerline mounted, double volute casing with optional double-suction, first-stage impeller (DMX)

Typical process parameters

- Flows to 5,678 m³/h (25,000 gpm)
- Heads to 2,712 m (8,900 ft)
- Suction pressures to 146 bar (2,115 psi)
- Pressures to 275 bar (4,000 psi)

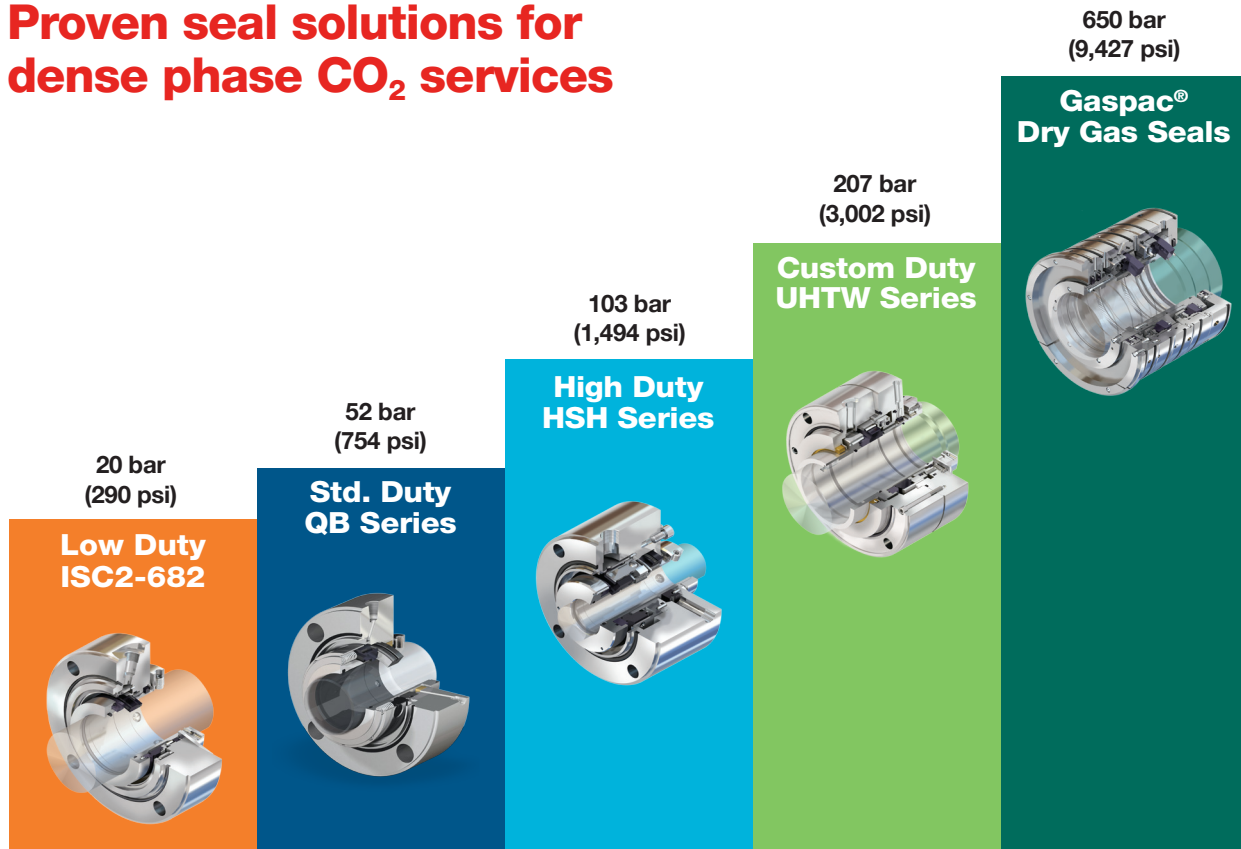
Extra heavy-duty, high-pressure, multistage barrel pumps

API 610 (BB5), latest edition; tandem and opposed impeller configurations; diffusor or volute design; single-diameter balance drum (WCC, HDO/HSO and WIK/WIKO)

Typical process parameters

- Flows to 4,000 m³/h (17,610 gpm)
- Heads to 7,000 m (23,000 ft)
- Differential pressures to 650 bar (9,425 psi); higher pressures available

Proven seal solutions for dense phase CO₂ services



The Flowserve portfolio includes seals ideal for a wide variety of CO₂ applications.

For transportation and injection, CO₂ is compressed into a dense phase that demonstrates properties of a liquid and a gas. Its density and lubricity plus impurities can significantly affect mechanical seal selection and performance.

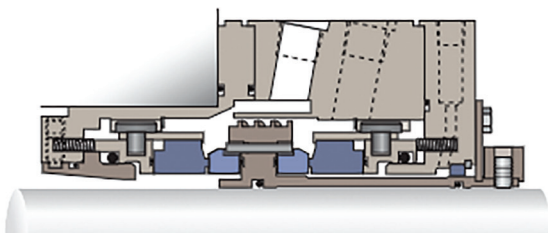
The gas-like viscosity of dense phase CO₂ makes it difficult to maintain fluid film thickness with traditional liquid seals. Its liquid-like density can create high leakage rates and the potential for atmospheric-side icing with gas seals.

These challenges can only be addressed with advanced technology and innovative engineering solutions. The Flowserve seal portfolio includes proven products for a wide variety of CO₂ applications, including high-pressure and supercritical, dense phase services. Our CO₂ seal specialists can support you in selecting the seal most appropriate for your application.

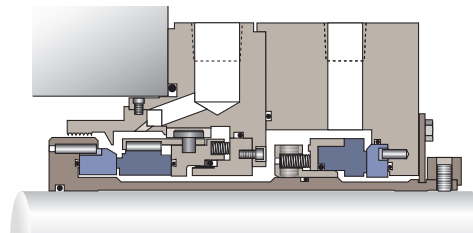
DHTW/DHTW and UHTW/GSLW seals provide reliable gas-liquid performance

The unique precision seal face topography of these pusher-type mechanical seals from Flowserve provides the hybrid gas-liquid performance needed for CO₂ applications without significant auxiliary systems. They are custom configured to maximize equipment uptime and availability in critical services.

- Dual **DHTW/DHTW** face-to-face seals are suitable for heavy-duty applications requiring zero process emissions.
- Dual **UHTW/GSLW** face-to-back seals are suitable for higher-pressure flashing fluids such as CO₂, ethane, ethylene and LPG.



Dual DHTW/DHTW, face-to-face seal

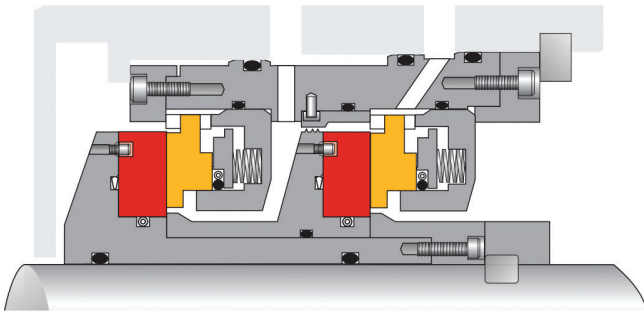


Dual UHTW/GSLW, face-to-back seal

Gaspac seals set the bar in high-pressure applications

Gaspac dry gas seals are engineered to perform over a wide range of operating limits, including supercritical or dense phase CO₂ conditions. Since 2000, more than 200 Gaspac seals from Flowserve have been installed on compressors and continue to reliably handle CO₂ and CO₂-mix gases.

Gaspac seals offer industry-leading technology that withstands the challenging conditions of high-density fluid and ensures high reliability and extremely low leakage. They have been proven in supercritical CO₂ processes that combine high speeds, temperatures and pressures.

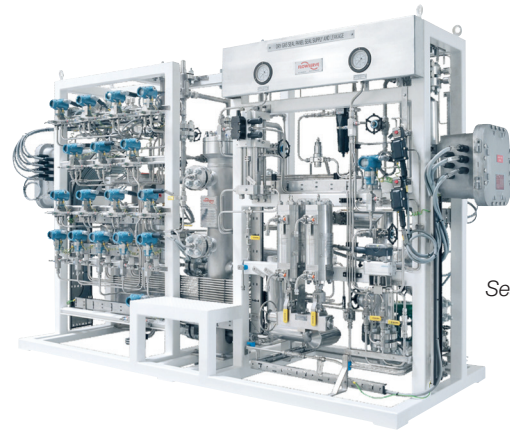


Cross-section of Gaspac L dry gas seal

Support systems to enhance reliability

To maintain the proper seal environment and extend seal life, Flowserve offers a wide range of seal support systems. Commonly used systems include the following:

- Flowserve seal gas panels ensure reliable operation and monitoring of seal performance.
- Our stand-alone Plan 54 and Plan 53B pressurized systems provide barrier fluid for zero process emissions.



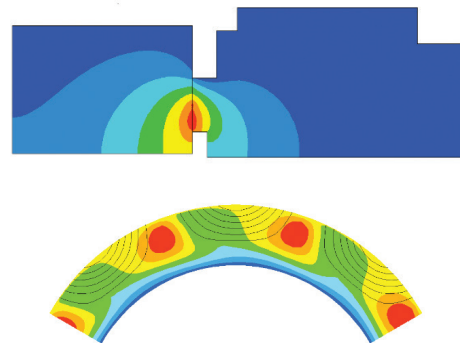
Seal gas panel

Superior design and testing capabilities advance seal performance

To ensure safer, more effective and predictable seal performance under all CO₂ conditions, Flowserve has developed some of the most advanced seal modeling and testing capabilities in the world.

Our seal specialists are constantly innovating wet and dry seal designs. They use advanced analytical techniques, including finite element analysis (FEA) and specialized multi-physics models, to explore and develop new microfeatures and seal face topographies to improve performance.

They have also developed a first-of-its-kind testing facility that can mirror pump operating conditions in CO₂ environments — including dense phase — in order to verify seal performance.



Enhanced finite element analysis predicts temperature and pressure response.



Our commitment to energy transition

At Flowserve, our approach to energy transition begins and ends with our purpose: to make the world better for everyone. We understand that when we enable our customers to tackle climate change and address increasing energy demands through our innovative flow control solutions, we can make the world better — now and for generations to come.

Our approach is threefold. We are diversifying, decarbonizing and digitizing to support the global energy sector's transformation toward low carbon sources.



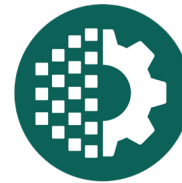
DIVERSIFICATION

Our innovative portfolio of flow control solutions and services will support energy systems around the world to diversify the energy mix and adopt cleaner sources of energy.



DECARBONIZATION

We will support the reduction of energy-related CO₂ emissions across the mix of energy sources through our innovative portfolio of flow control solutions and services.



DIGITIZATION

We will enable improvements in efficiency, productivity, sustainability and safety of energy systems around the world through our digital solutions and services.

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