ENABLING ENERGY TRANSITION TECH ARTICLE

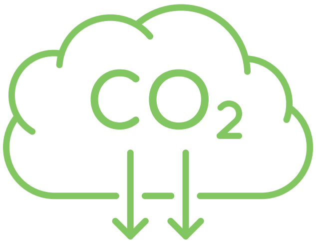
Proven Seal Technologies for CO_2 Capture and Supercritical Applications

Ensure the success of your energy transition initiatives with industry-leading expertise

DIVERSIFY | DECARBONIZE | DIGITIZE

Advanced seal technologies for CCUS and sCO_2 applications support energy transition initiatives

Companies increasingly are prioritizing energy transition initiatives to reduce greenhouse gas emissions known to cause climate change. They're also taking significant steps to operate more efficiently. Traditional fossil fuels are expected to remain an essential feedstock for some time to keep up with energy demand; nonetheless, carbon dioxide (CO_2) and other greenhouse gases emitted during industrial processes must be reduced.



Critical technologies will enable this energy transition. Among them is carbon capture usage and storage (CCUS), in which CO_2 emissions are captured from sources like coal-fired power plants and industrial processes. The CO_2 is then reused on-site, shipped to other industrial users, or stored underground to prevent its release into the atmosphere.

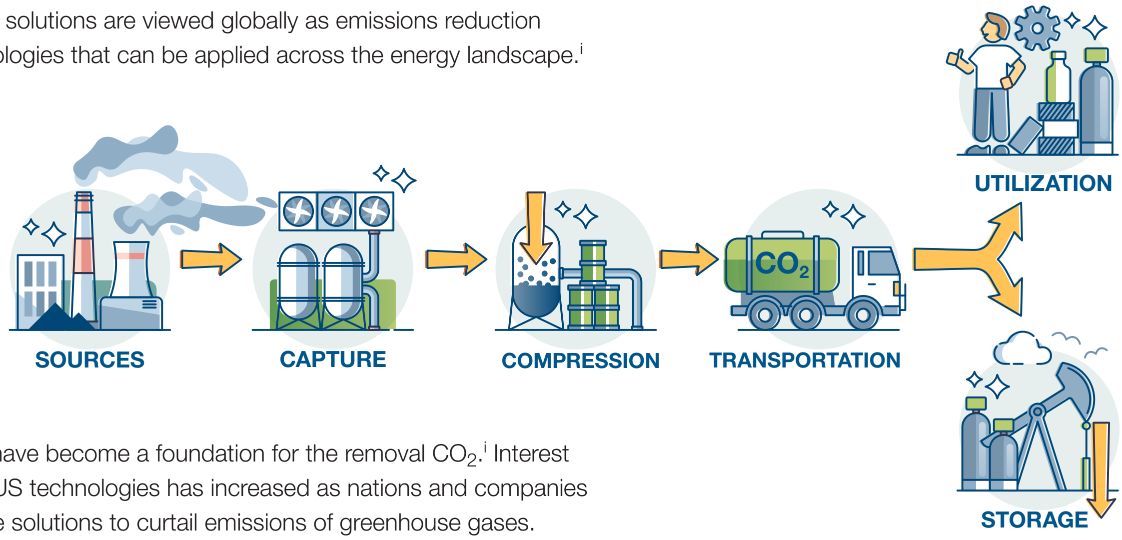
In the past decade, studies have been conducted to determine the efficiency and other benefits of using CO_2 as a motive fluid in power generation thermal processes. An advanced approach has been developed in which supercritical CO_2 (sCO_2) replaces steam as the working fluid that drives the power generation turbine. The cycle is operated above the critical point of CO_2.

While compressors and turbines are essential equipment for this process, seals are the key components. They ensure high performance of turbomachines along with compliance with low emissions requirements.

And Flowserve is the first to develop a proven and tested seal design that delivers industry-leading solutions for both compressor and turbine technologies. We engineer and manufacture superior seal technology installed in CCUS applications around the world. And, for the first time, previously unexplored seal technology for sCO_2 turbomachines has been tested and proven by Flowserve.

Capturing and reusing or storing CO_2

CCUS solutions are viewed globally as emissions reduction technologies that can be applied across the energy landscape.[i]



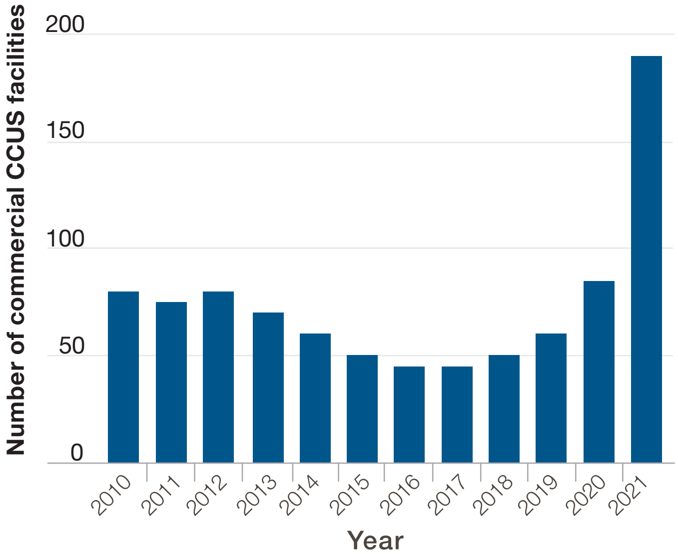
They have become a foundation for the removal CO_2.[i] Interest in CCUS technologies has increased as nations and companies pursue solutions to curtail emissions of greenhouse gases. Indeed, strengthened climate goals and new investment incentives led to the announcement in 2021 of plans to construct more than 100 CCUS facilities throughout the world.[i]

Expanding pipeline of commercial CCUS facilities[ii]

After years of slow progress, new investment incentives and strengthened climate goals are building momentum behind CCUS, according to the International Energy Agency (IEA). The total number of commercial CCUS facilities (in development, under construction and in operation) worldwide has been growing since 2018.

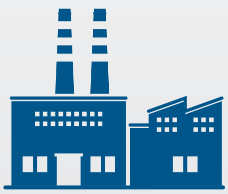
The trend is expected to continue because CCUS is the only technology that contributes both to reducing emissions directly and removing CO_2 to balance emissions that are challenging to avoid, which the IEA said is a critical part of achieving net-zero goals.

Growth in CCUS facilities



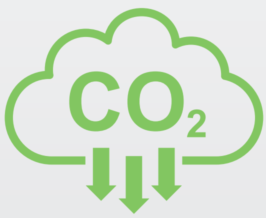
What is carbon capture?

CCUS systems capture CO_2 from power generation or industrial facilities that combust either fossil fuels (coal, natural gas or oil) or biomass for feedstock. CO_2 is captured during one of three steps in a power generation plant or industrial process:



Pre-combustion

CO_2 is trapped by partially burning the feedstock fossil fuel to form a synthetic gas and separate the CO_2 as well as hydrogen, which can be stored for use as a fuel.



Post-combustion

CO_2 is scrubbed from the exhaust gases after burning the feedstock fossil fuel.

Oxyfuel combustion

CO_2 is separated by burning the feedstock fossil fuel in 100% oxygen instead of air; the resulting exhaust gases consist mostly of water vapor, which is cooled and condensed, and pure CO_2, which is collected.

If not used on-site, the captured CO_2 can be compressed and transported for use in a range of applications, including sCO_2 power generation plants. The captured CO_2 also can be injected into deep geological formations (including depleted oil and gas reservoirs) for permanent storage.

CCUS technology leader and total-solutions provider

Flowserve offers deep expertise in products and services that support CCUS technologies and meet emission rate requirements. We are the leading service provider for dry gas seal retrofits, high end compressor seal troubleshooting, seal support engineering and world-class gas conditioning systems.

Our specialists understand how the physical properties of CO_2 dramatically affect mechanical seal selection and performance in CCUS systems. Gas-like viscosity makes it difficult to maintain fluid film thickness with traditional liquid seals. 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 technologies and innovative engineering solutions. Flowserve provides sealing solutions for dense-phase or highly compressed CO_2 service.[iii] Our proven products include:

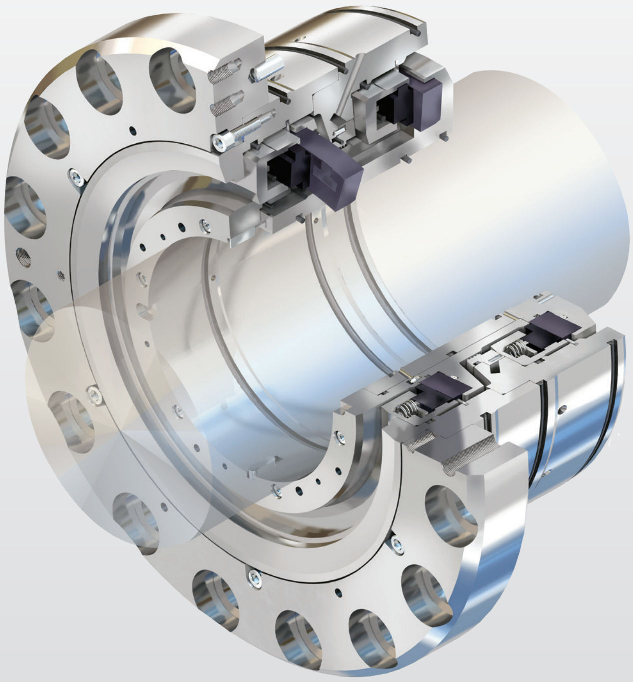
- Gaspac® dry gas seals incorporate non-contacting, lift-off technology to provide low break-away torque, reliable performance and the lowest leakage rate.
- Turbopac™ oil-lubricated seals feature a bi-directional design that responds to pressure drops to optimize safety and reliability for high-speed and high-pressure applications.

Gaspac seals ideal for wide range of CO_2 applications

Gaspac dry gas seals are engineered to perform over a wide range of operating limits, including supercritical CO_2 conditions.

Two lift-off face patterns — bi-directional and uni-directional — provide high film stiffness and damping capabilities that maintain the gas film under slow roll conditions as well as high speeds. Low break-away torque is provided by non-contacting, lift-off technology.

Flowserve has been delivering Gaspac seals for CO_2 applications since early 2000. Since that time, more than 200 seals have been installed on compressors handling CO_2 and CO_2-mix gases.



Gaspac L seal

Increase turbine efficiency by replacing steam with sCO_2

Electricity is generated around the world with steam created by burning fossil fuels or from the use of solar collectors or nuclear reactors. But supercritical CO_2 technologies are about to change that.

Pressurized water is boiled into steam and then expanded through a turbine to turn a generator. This is called the *Rankine cycle*. In conventional power plant designs, it's only 33% efficient. Most of the heat created — 67% — is not converted into electricity and is typically released as waste.[iii]

But, there's a better process that supports energy transition initiatives and can have efficiencies of 50% or more.[iii] Turbines are being developed based on a modified Brayton cycle that utilizes sCO_2 as the working fluid. Due to higher CO_2 power density, for the same electrical power output, the turbomachine's size is much smaller.

What is supercritical CO_2?

sCO_2 is a fluid state of carbon dioxide after it has been heated above 31.1°C (87.9°F) and is subjected to pressures above 7.39 MPa (1,071 psi).

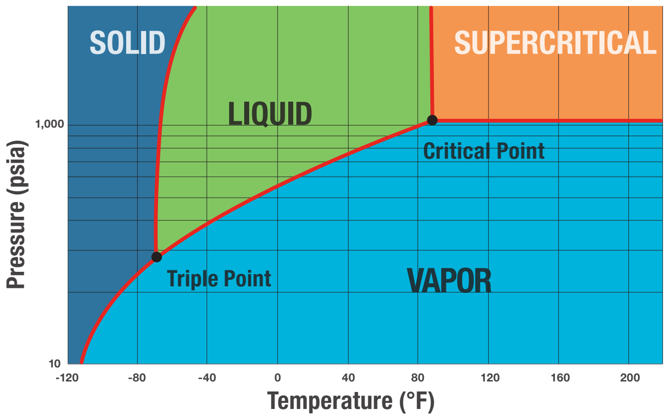
In its supercritical phase, CO_2 exhibits properties and behaviors between a liquid and a gas; it possesses liquid-like densities with gas-like diffusivity, surface tension and viscosity.

This phase of CO_2 is commonly used as a solvent in chemical extraction processes due to its high solubility, low toxicity and minimal net effect on the environment. Interest in sCO_2 for power generation is escalating because of these benefits.

However, the use of sCO_2 for power generation is challenging for seals. It undergoes large changes in density with small changes in pressure or temperature — a major plus for its efficiency in powering turbines, but a challenge for sealing due to the quick change in gas conditions caused by expansion across the seal gap. As a result, the behavior of sCO_2 can be difficult to predict due to a combination of factors:

- High density (heat generation due to windage)
- High cooling effect during expansion
- High volume increasing during expansion

When CO_2 becomes supercritical



The business case for sCO_2

Replacing steam with sCO_2 as the working fluid for power generation and other industrial processes means it takes less work to convert a given amount of thermal input to electricity, regardless of the source of heat (fossil fuel, nuclear or solar).[iii]

There are additional clear benefits: sCO_2 is non-toxic, non-flammable, inert, and does not damage the environment if there is a leak or spill.

Thanks to the properties of sCO_2, the footprints of the turbomachinery and the power plant as a whole can be smaller. As a result, capital equipment investment and operational costs can be reduced.[iii]

Another benefit of using sCO_2 to power turbines is that its liquid-like density needs less compression and therefore saves energy. At its critical point, sCO_2 is about half the density of water and easier to compress than steam. The compression phase normally accounts for 25%[iii] of the work performed inside a conventional power generation system. With sCO_2 as the working fluid, compression requirements are dramatically reduced and the energy savings enhance the turbine's overall efficiency. It also takes less work to cycle it back to the heat source for re-expansion.

Proving seal reliability for sCO_2 applications

Unlike the knowledge base established with decades of successful experience with CCUS systems, industry-wide understanding of sCO_2 technologies, especially seals, is in the early stages of research and development (R&D). Compressor seals have never been required to operate at such high pressures, speeds and temperatures as those needed for supercritical gas applications, such as:

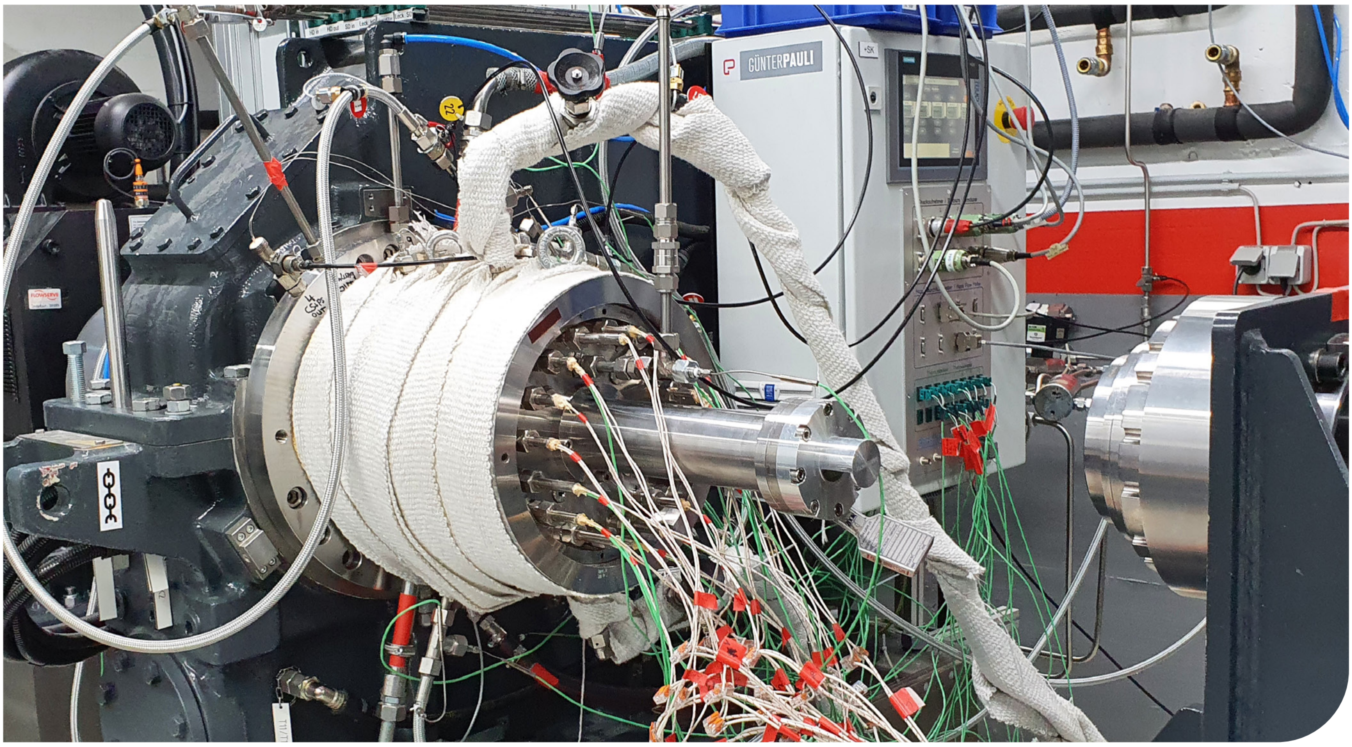
- Pressures up to 200 bar (2,901 psi)
- Tip speeds above 200 m/s (656 ft/s)
- Temperatures above 250°C (482°F)

It's been unexplored territory — with some seal manufacturers considering whether to offer products that have not been tested under all three conditions above, applied simultaneously.

Flowserve is the first seal vendor able to offer fully tested seals in the challenging environment with advanced control of sCO_2 fluid conditions.

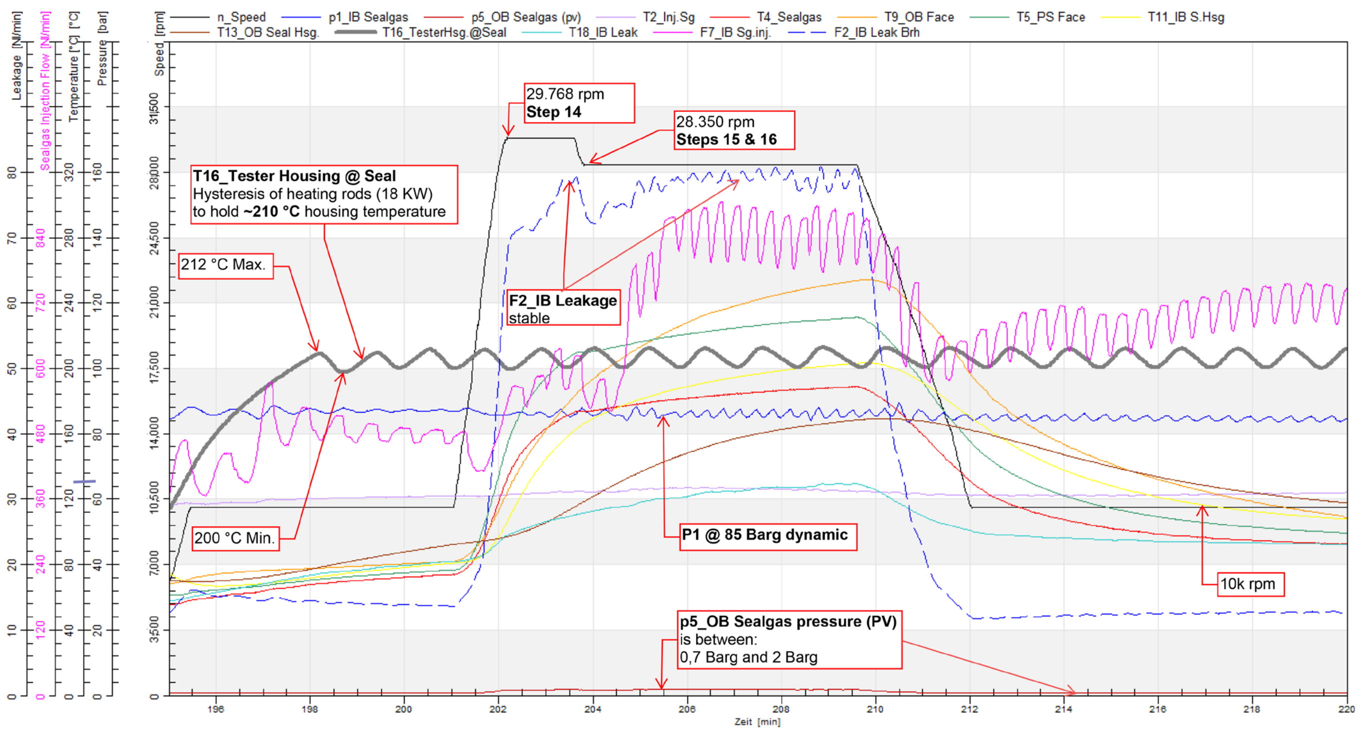
We also are the first seal provider with the capability to offer testing that's able to mirror the extreme environment of sCO_2 turbomachines. Anticipating the increased priority placed on energy transition initiatives, we built a test rig in our Dortmund, Germany, facility to demonstrate how well our sealing technology performs in sCO_2 applications. We also sought to validate seal performance to give compressor and turbine original equipment manufacturers (OEMs) huge advantages in terms of design, analysis and testing of their machines.

To demonstrate performance capabilities, the Flowserve Dortmund test rig is equipped with a heating system that simulates seal housing operating conditions in compressors and turbines. Using the facility, Flowserve engineers proved that with key modifications, Gaspac seals can reliably withstand the high temperatures, pressures and speeds of sCO_2 applications, minimizing the leakage.



The sCO_2 test rig at Flowserve's facility in Dortmund, Germany

Sample sCO_2 test results



The diagram shows a portion of the whole sCO_2 Gaspac seal test steps and summarizes the main parameters' trends. It is worth noting the accurate control of testing parameters as well as the stable trend and repeatability of the leakage rate at temperature and speed variations.

Seal supplier for the first-ever sCO_2 pilot projects

The positive sCO_2 seal test results prepared Flowserve to become the preferred seal vendor involved in the world's first two sCO_2 pilot plants:

- In Texas, a fully integrated power plant with 10 MW electric output will be commissioned later in 2022.
- In Spain, a first-of-its-kind, 1 MW-scale plant in which molten salts will be heated by concentrated solar energy

However, the heating sources are vastly different.

At the power plant in Texas, advanced boilers will combust fossil fuels to heat CO_2 to supercritical levels and drive turbomachinery. The system is designed to achieve thermal efficiency greater than 50%.

Meanwhile, the facility in Spain will utilize mirrors to concentrate sunlight onto a receiver to heat molten salt, which in turn will raise the temperature of CO_2 to supercritical levels to drive turbines. Unlike power plants that burn fossil fuels, the concentrated solar plant (CSP) will not emit CO_2 or other greenhouse gases that contribute to climate change.

While one heat source is conventional and the other is leading-edge and renewable, both of these pilot projects are designed to determine how much sCO_2 can increase efficiency while cutting costs — and achieve national and corporate goals for decarbonation. The success of the emerging energy generation technologies utilizing sCO_2 is closely related to the availability of industry-leading turbomachinery shaft seal solutions supplied by Flowserve.

Achieve your energy transition goals with an expert partner

Successfully lead your company's energy transition initiatives by partnering with Flowserve to incorporate proven CCUS and/or sCO_2 technologies. Our design and applications engineers understand the challenges associated with sealing dense-phase and supercritical CO_2; we pioneered many of the technologies the industry relies upon today.

In addition, Flowserve developed unrivaled test capabilities to prove seal performance on which you can rely for your decarbonization and energy transition projects. Our unmatched global experience and diversified resources help customers reduce emissions, operate more efficiently, and build more sustainable companies. And as your partner, we can support you throughout your energy transition journey.

i IEA, "Carbon capture, utilisation and storage," January 11, 2022, https://www.iea.org/fuels-and-technologies/carbon-capture-utilisation-and-storage (accessed January 14, 2022).
ii Flowserve, "CO2 Transportation and Injection Pumps," 2011, https://www.flowserve.com/sites/default/files/2016-07/ps-30-17-e.pdf (accessed January 14, 2022).
iii Machine Design, "Supercritical CO2: The Path to Less-Expensive, "Greener" Energy," Sept. 10, 2018, https://www.machinedesign.com/mechanical-motion-systems/article/21837123/supercritical-co2-the-path-to-lessexpensive-greener-energy (accessed January 14, 2022).

FLOWSERVE

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 CO_2 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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