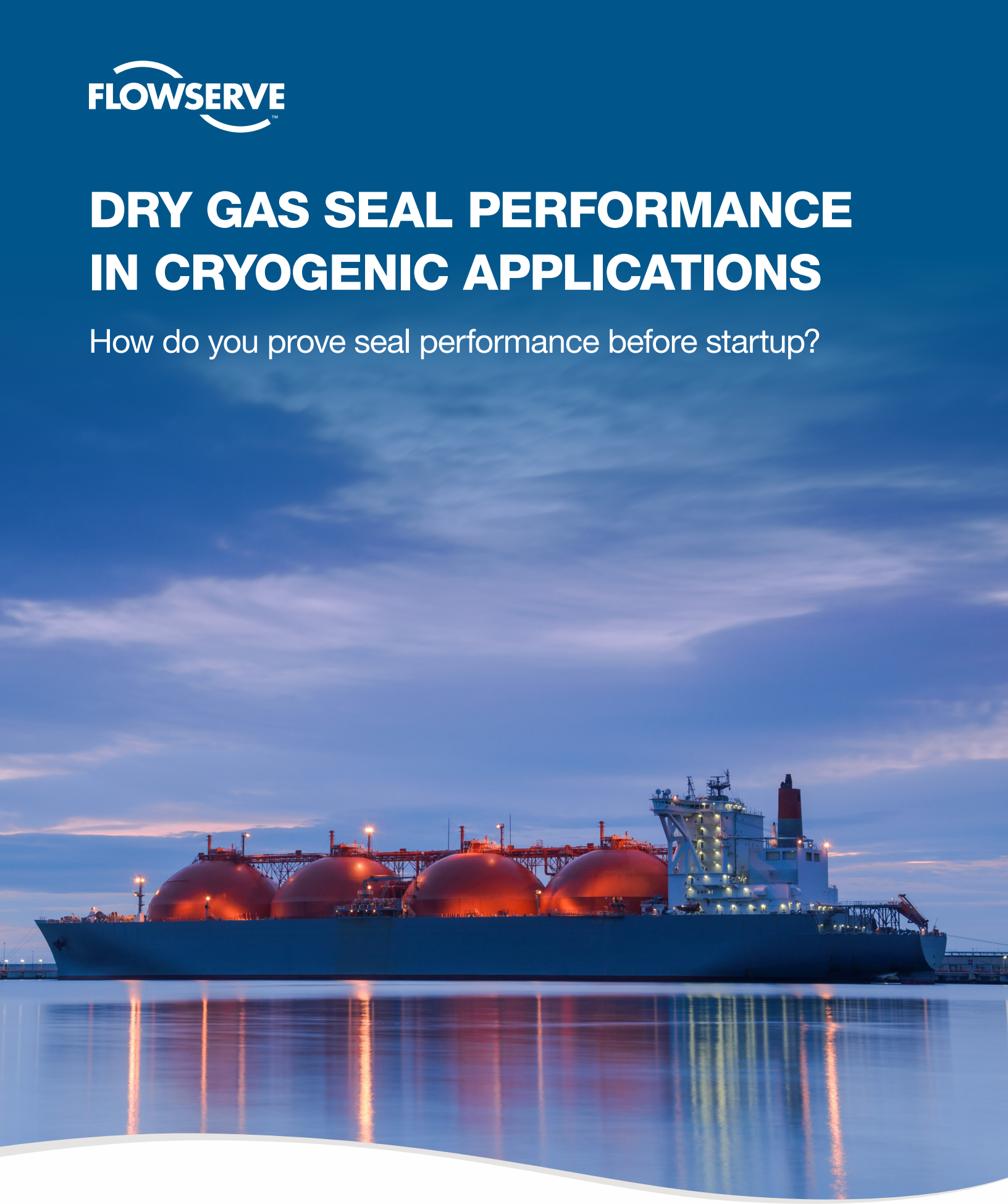
FLOWSERVE

# DRY GAS SEAL PERFORMANCE IN CRYOGENIC APPLICATIONS

How do you prove seal performance before startup?



*Experience In Motion*

# Executive Summary

As industries such as LNG, hydrogen, industrial gases, and low-carbon energy systems continue to expand, equipment is increasingly required to operate in extreme cryogenic environments. Temperatures can fall below -100°C and, in some applications, approach the boiling point of liquid nitrogen.

While compressors and expanders often receive most of the engineering attention, sealing technology plays an equally important role in ensuring reliability, safety, and operational continuity. Dry gas seals operating in cryogenic conditions must withstand severe thermal gradients, repeated startup cycles, material contraction, and changing gas properties while maintaining reliable performance.

This paper explores the engineering challenges associated with cryogenic sealing, the importance of dynamic validation testing, and the characteristics of dry gas seal technologies that have demonstrated successful performance in low-temperature applications.



# The Growing Importance of Cryogenic Machinery

Cryogenic processes extend well beyond one market. LNG growth remains a major driver, while low-temperature equipment also supports industrial gas separation, hydrogen processing, ethylene refrigeration, nitrogen expansion and other energy-transition or specialty-gas applications.

In an LNG value chain, cold-gas compression can appear in liquefaction and refrigeration cycles, boil-off gas recovery, storage and transportation. Compressor-expanders commonly combine multiple compression stages with an expansion stage to remove energy from the process and support refrigeration or liquefaction. Other compressors may simply receive a very cold gas and must operate reliably without allowing unintended phase change.

Today, rotating equipment operates in low-temperature environments across a broad range of applications including:

- LNG liquefaction and refrigeration cycles
- Boil-off gas recovery and recompression
- Hydrogen production and processing
- Industrial nitrogen expansion systems
- Air separation units
- Ethylene and methane refrigeration
- Specialty gas and low-temperature process systems

As these industries continue growing, equipment owners are demanding higher reliability while simultaneously operating at increasingly challenging process conditions.

## Why Cryogenic Sealing Is Different

Dry gas seals are established in conventional gas compression, but cryogenic duties introduce additional engineering considerations and technical challenges. Four mechanisms are especially important.

**Material Contraction**
At cryogenic temperatures, metallic and nonmetallic components do not contract identically. Small dimensional changes can affect critical seal clearances, face loading, and secondary sealing elements.

**Dynamic Startup Conditions**
Trips, restarts, rapid pressure changes and thermal cycling can challenge a sealing system more severely than stable operation.

**Thermal Gradients**
The shaft, housing and seal assembly may cool at different rates. The resulting gradients are especially important during cooldown, heat-up, startup and shutdown.

**Gas Property Changes**
Density, viscosity and leakage behavior vary with temperature, pressure and gas composition. These changes influence lift, heat generation, flow through restrictions and seal-system performance.

## How Cold is Cryogenic? Putting Temperatures Into Perspective



**–40°C — Extreme winter cold**

Cold enough that exposed skin can freeze in minutes. Think of the harshest Arctic winter conditions, where even everyday equipment can struggle to operate.



**–78.5°C — The temperature of dry ice**

Unlike regular ice, dry ice is frozen carbon dioxide. It is so cold that it turns directly into gas instead of melting into liquid.



**–100°C — Beyond Earth's usual extremes**

Even colder than the lowest naturally recorded air temperature on Earth (–89.2°C). This is no longer ordinary winter cold.



**–170°C — Colder than liquid natural gas**

Natural gas is cooled to around –162°C to turn it into liquid for storage and transportation. –170°C is colder still, entering the range of demanding cryogenic applications.



**–196°C — Liquid nitrogen cold**

The temperature of liquid nitrogen at atmospheric pressure, used for ultra-fast freezing and long-term preservation of biological materials.

## Why does this matter for sealing?

At these temperatures, materials can shrink, become less flexible, and behave differently under pressure. A seal that performs reliably at room temperature may face entirely different challenges in cryogenic service.

# What Makes a Dry Gas Seal Suitable for Cryogenic Service?

Not all dry gas seal systems are qualified equally for cryogenic operation.

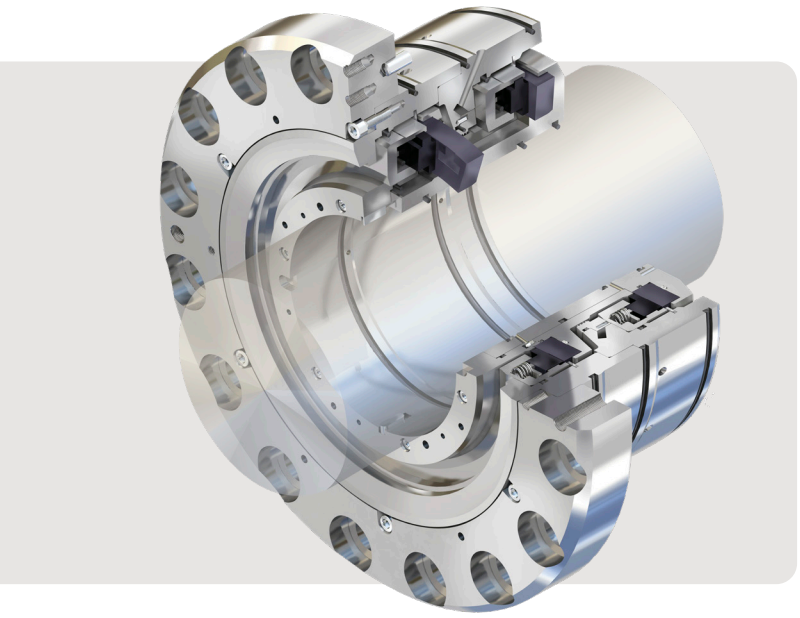
Several factors are critical when evaluating seal suitability:

- **Proven Low-Temperature Design**
  The seal must be designed with materials and geometries capable of operating reliably under cryogenic thermal conditions.
- **Secondary Sealing Technology**
  Special attention is typically given to dynamic sealing elements that must maintain flexibility and sealing performance at extremely low temperatures.
- **Startup Capability**
  The ability to repeatedly start equipment after exposure to cryogenic temperatures is often a more demanding requirement than steady-state operation.
- **System Integration**
  A successful cryogenic installation depends not only on the seal itself but also on the complete seal support system, process gas management, and equipment configuration.

## Flowserve technology scope

Successful cryogenic sealing depends on more than an individual seal design. It requires a combination of compressor seal technology, separation sealing, system integration, application engineering and validation under representative operating conditions.

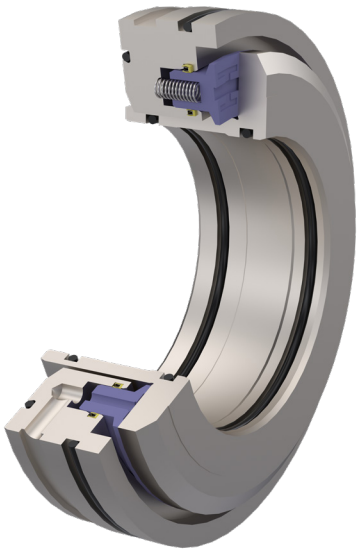
GASPAC dry gas seals use non-contacting lift-off technology to establish a stable gas film between the seal faces during operation. Depending on the application, the seal can incorporate Flowserve's bidirectional T-Groove technology or Advanced Pattern Groove, APG, technology. These proven face-pattern technologies are designed to provide high gas-film stiffness and damping, supporting reliable separation of the seal faces across changing operating conditions, including slow-roll operation, startup, shutdown and high-speed service.



The GASPAC portfolio includes single, double and tandem arrangements that can be configured around the requirements of the compressor and process. For compressor-expander applications, GASPAC-S® provides a configuration suited to the specific architecture and operating demands of this equipment.

**Flowserve supports these requirements with a portfolio of turbomachinery sealing solutions centered on the GASPAC® compressor seal family. GASPAC seals are engineered for demanding gas-handling applications, with configurations selected to match the machine design, gas composition, pressure, temperature, speed and operating sequence.**

Where the overall sealing system requires isolation between the dry gas seal and the bearing housing, Flowserve can also provide separation-seal solutions selected for the application. These solutions help prevent bearing oil from entering the dry gas seal area while managing the use of separation gas.



Flowserve's separation-seal portfolio includes technologies designed to reduce gas consumption, operating costs and associated emissions when compared with conventional separation-seal arrangements. Product selection depends on the machine configuration, available separation-gas supply, operating conditions and safety requirements.

Together, Flowserve compressor seals, separation seals, seal-support systems and engineering expertise provide an integrated approach to managing the complete sealing system. This capability is reinforced by application-specific testing that can evaluate seal behavior under conditions representative of the customer's operating environment.

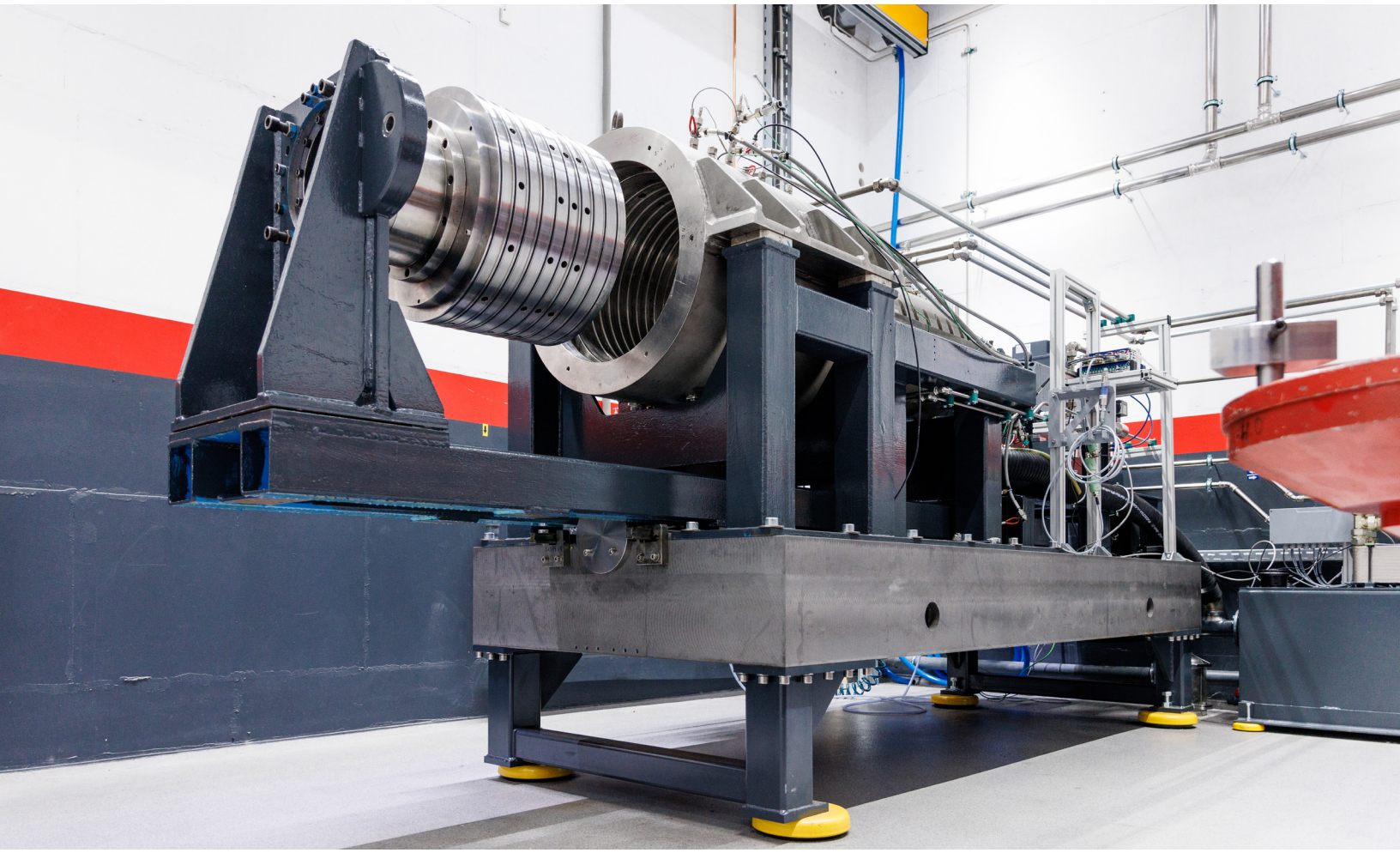
# How do you know a design will perform in the real world?

For critical LNG, hydrogen, nitrogen and other cryogenic duties, calculations are necessary but may not fully reproduce coupled thermal, mechanical and fluid-dynamic behavior. Application-specific testing supplies evidence that the seal and the wider system can function across the conditions that matter to the customer.

## Testing close to real operating conditions can help OEMs and end users:

- validate startup and shutdown behavior
- assess performance during pressure changes and thermal cycling
- support technical qualification and bid requirements
- reduce uncertainty during project execution
- document performance before commissioning
- strengthen confidence in the complete equipment package

**The differentiator is ownership of validation: investing in the capability to demonstrate performance before delivery, under conditions selected to represent the customer's operating environment.**



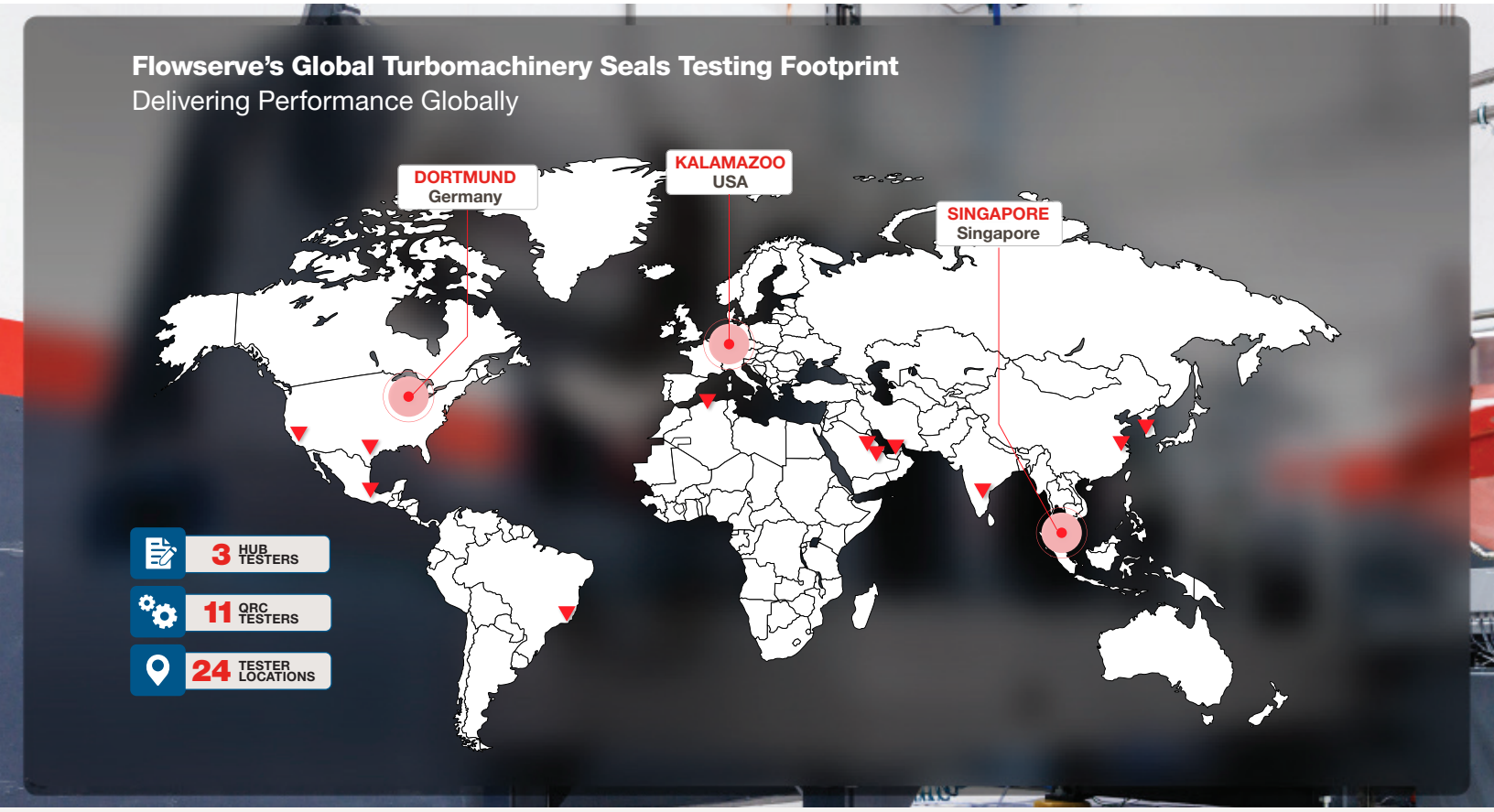
# Pushing the Limits of Cryogenic Validation: Flowserve's Cryogenic Testing Advantage

For cryogenic applications, testing must go beyond conventional product qualification. To accurately assess seal performance, validation programs should replicate the thermal, mechanical and operational conditions that equipment will experience in service. This includes startup and shutdown sequences, thermal cycling, pressure fluctuations, shaft rotation and other transient operating conditions that can significantly influence seal behavior.

Flowserve has invested in the industry's most comprehensive turbomachinery seal testing networks, combining specialized validation capabilities with local service and support resources.

**This network includes:**

- 24 testers worldwide
- Dedicated hub facilities for specialized testing and validation
- 10 Quick Response Centers (QRCs) with testing capability
- High-speed, high-pressure and application-specific testing resources supported by experienced engineering teams




### Hub Tester Locations

| Dortmund, Germany | Kalamazoo, USA | Singapore, Singapore |
|---|---|---|
| Total 7 | Total 3 | Total 2+ |
| 1 Ultra High Pressure | 1 High Pressure | XXL Jumbo Size |
| 1 High Speed | 1 High Speed | |

### QRC Tester Location / Implementation of QRC

| | | | |
|---|---|---|---|
| **São Caetano, Brazil** | 2024 | **Tlaxcala, Mexico** | 2015 |
| **Dubai, United Arab Emirates** | 2009 | **Qatar** | 2019 |
| **IVK, South Korea** | 2010 | **Saudi Arabia** | 2022 |
| **Sanmar, India** | 2013 | **Algeria** | 2025 |
| **Suzhou, China** | 2014 | **Pasadena, USA** | 2026 |

Specialized cryogenic validation is conducted at facilities equipped for low-temperature testing. A key differentiator within Flowserve's validation capabilities is the ability to perform dynamic cryogenic testing using liquid nitrogen.

At Flowserve's Dortmund facility in Germany, engineers can simulate operating conditions approaching -170°C under dynamic conditions, allowing seals to be evaluated during startup, shutdown, pressurization, thermal cycling, and high-speed operation.

Unlike a static laboratory test, these programs replicate conditions encountered in actual turbomachinery operation, including:

- Rapid cool-down events
- Cryogenic startup sequences
- Pressure changes
- Thermal cycling
- Dynamic shaft rotation
- Seal gas performance at low temperatures

The objective is not only to verify seal integrity, but also to understand how the complete sealing system behaves under realistic process conditions.

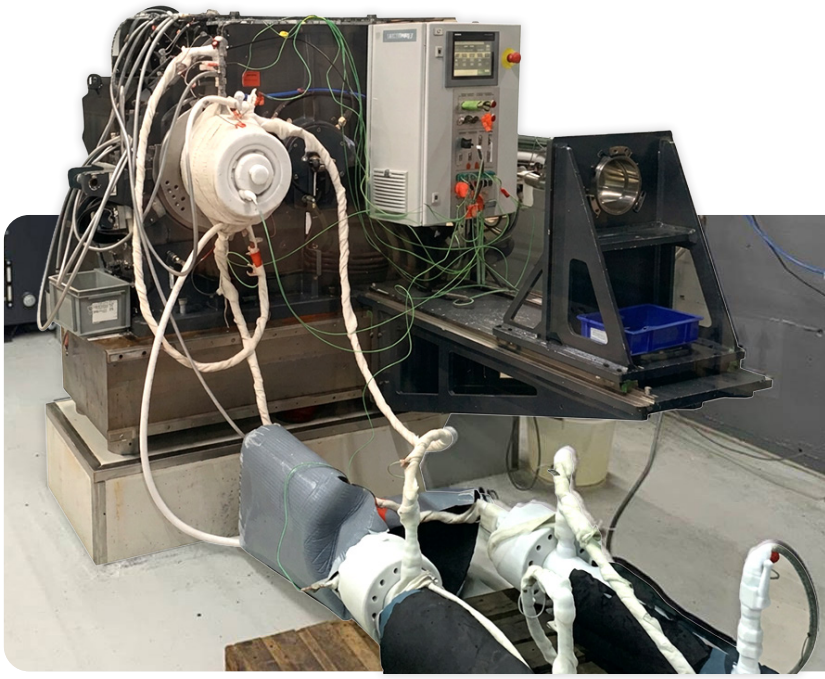
## Proven Through Application-Specific Testing

Recent validation programs demonstrate how cryogenic testing is being used to support both end users and OEM partners.

For an LNG Cold Box nitrogen refrigeration application, startup testing successfully evaluated dry gas seal performance at temperatures approaching -140°C during simulated operating conditions.

For a hydrogen/nitrogen expander application, a full cryogenic Factory Acceptance Test validated seal operation under dynamic conditions near-100°C, confirming performance through both static and rotating phases of operation.

These programs provide more than seal validation. They help equipment manufacturers demonstrate reliability, document performance, and support customer confidence and risk mitigation before equipment enters service.



## More Than Two Decades of Cryogenic Experience

Testing is important, but long-term field experience remains equally valuable.

Flowserve dry gas seals have operated successfully in cryogenic services for more than thirty years across:

- LNG-related systems
- Hydrogen-rich gas applications
- Nitrogen expanders
- Ethylene refrigeration
- Methane compression
- Syngas processing
- Industrial gas facilities

The historical operating record includes documented applications reaching temperatures below **-190°C**, demonstrating successful operation across some of the most demanding cryogenic environments encountered in industry.

# Conclusion: confidence comes from the complete evidence chain

Cryogenic sealing is fundamentally different from conventional gas compression because temperature changes the behavior of materials, gases and equipment interfaces. Reliable performance requires suitable seal technology, disciplined system integration, experience with transient operating conditions and evidence from testing that represents the real duty.

Flowserve brings these elements together through application expertise, GASPAC compressor seal solutions, specialized cryogenic validation and a global turbomachinery seal service network. This combination helps OEMs and equipment owners reduce uncertainty and build confidence before commissioning and throughout the operating lifecycle.

**Planning a cryogenic compressor or expander application?**

Contact Flowserve to discuss the operating envelope, sealing-system requirements and an appropriate validation strategy.

www.flowserve.com/support/contact-us

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